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SEA KING MK. 50 HELICOPTER FLIGHT CONTROL SYSTEM - A MATHEMATICAL MODEL OF THE AFCS (ASW MODE).

by Christopher R. Guy

C. R. GUY

Approved for Public Release.

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A MATHEMATICAL MODEL OF THE AFCS (ASW MODE)

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SUMMARY

A mathematical model for the anti-submarine warfare (ASW) mode of the automatic flight control system (AFCS) for the Sea King Mk.50 helicopter is presented. An outline of the ASW mode facilities is given first, followed by a description of the mathematical model, which includes a representation of each major element of the aircraft system.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories,
Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

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16. *ABSTRACT*

A mathematical model for the anti-submarine warfare (ASW) mode of the automatic flight control system (AFCS) for the Sea King Mk.50 helicopter is presented. An outline of the ASW mode facilities is given first, followed by a description of the mathematical model, which includes a representation of each major element of the aircraft system.

CONTENTS

1. INTRODUCTION

The operation of the automatic flight control system (AFCS) for the Sea King Mk.50 helicopter is conveniently subdivided into two modes, the autostabilizer/autopilot mode and the anti-submarine warfare (ASW) mode. The object of this report is to describe a mathematical model of the system in the ASW mode. This is used in conjunction with models representing the flying controls (Ref. 1) and the autostabilizer/autopilot mode of the AFCS (Ref. 2). Together, the flying controls and the AFCS form the control systems for the helicopter. In turn, the control systems model combines with mathematical models of the aerodynamics/kinematics and sonar cable/transducer to form a complete helicopter/sonar dynamics model. An overall block diagram for the helicopter/sonar system is shown in Figure 1.

The ASW mode model presented here has some similarities to the hover coupler representation used in the Wessex helicopter mathematical model developed by Packer at Weapons Research Establishment† (Refs 3–6). In addition, a simplified model of the Sea King AFCS, which includes the ASW mode, has been described in Reference 7. However, the model presented here makes representations of the elements forming the ASW mode of the AFCS used in the aircraft (unlike the model outlined in Reference 7, which represents only overall control laws). A full description of the AFCS used in the aircraft is given in References 8–11 and parts of the text of this report are taken from these references.

Section 2 of this document describes the facilities provided by the ASW mode of the aircraft AFCS : radio altitude hold, transition down, doppler hover and air-sea rescue (ASR), cable hover and transition up. Section 3 outlines the mathematical model; this is subdivided into the inertial height smoother, the radio altitude hold/ASW collective channel and the pitch and roll channels. Block diagrams and flow charts for the model are presented (Figs 2 to 8) and its equations are given in Appendix 1. The block diagrams and flow charts are constructed from diagrams of the physical system contained in References 8 to 10 and from circuit diagrams and data for the AFCS supplied by Louis Newmark Ltd, manufacturers of the equipment. They form a link between the physical system and the mathematical model. The equations representing the characteristics of each element can be deduced from the block diagrams.

Those parts of Figure 1 which relate to this report are the blocks representing doppler radar/radio altimeter and AFCS ASW mode. Further breakdowns of the system are shown in Figs 9 to 14 (taken from Ref. 8). In these figures, the AFCS ASW mode facilities are represented by some of the inputs to the amplifier unit plus part of the amplifier unit itself. The remaining inputs and the remaining parts of the amplifier unit are covered in the AFCS autostabilizer/autopilot mode report (Ref. 2). The joining points between the ASW and autostabilizer/autopilot modes of the AFCS, which occur in the amplifier unit, are specified in the relevant sections of this report. Those parts of the flying controls shown in Figures 9 to 14 (servo valves, control runs etc.), are described in Reference 1.

2. ASW MODE FACILITIES OF THE AIRCRAFT

2.1 Radio altitude hold (Fig. 9)

Before engaging radio altitude hold, a datum height (set radio height) is pre-set by the pilot. The range of control is 0 to 500 ft (0 to 152 m). On engaging radio altitude hold, barometric altitude hold (Ref. 2) is disengaged automatically.

An inertial height smoother circuit in the collective channel provides smoothed height and vertical velocity information. This greatly reduces the up and down motion (due to waves) which would otherwise result from direct control of radio altitude relative to the sea surface. With radio altitude hold engaged, altitude is stabilized to the set radio height datum value.

† Now Defence Research Centre, Salisbury.

The pilot may change height with radio altitude hold engaged by altering the set radio height datum. When large height changes are demanded, 'open-loop' operation of the auxiliary servo unit has the effect of trimming the collective lever during the manoeuvre (see Refs 1 and 2). The lever returns approximately to its former position as the aircraft settles to the new value of altitude.

2.2 Transition down (Figs 10 and 11)

Transition down is the automatic manoeuvre which brings the aircraft from cruise conditions (within a specified band) to the hover, in readiness for the 'dunk' phase of ASW operations. Before initiating transition down, the aircraft is turned into wind, the autostabilizer/autopilot and radio altitude hold facilities are engaged and the AFCS doppler mode is selected. The altitude of the intended hover is set on the set hover height control. When the transition down switch is engaged, the aircraft begins a controlled descent to hovering altitude using radio height information, at the same time decelerating to zero groundspeed using doppler radar information; the manoeuvre is programmed to take about 80 s. Throughout the transition down, sideways drift is controlled from groundspeed information obtained from the doppler radar and the heading hold facility remains operative. At any time in the transition, the pilot may disengage the groundspeed or altitude control programmes.

2.3 Doppler hover and ASR facility (Figs 10 to 12)

At completion of the transition down, the aircraft hovers at zero groundspeed (using doppler sensing) and the set hover height (using radio altimeter sensing) while the sonar submersible unit is lowered. The yaw channel maintains constant heading (heading hold). The set hover height control may be used to ensure the required clearance over wave crests. In ASR operations, the auxiliary hover trim switch is engaged to enable the winch operator to manoeuvre the aircraft in plan-position over the sea surface using the hover trim controller. This operates in both the pitch and roll channels by controlling cyclic pitch.

2.4 Cable hover (Figs 13 and 14)

When the sonar submersible unit enters the water, the AFCS is switched manually from doppler mode to cable mode. Plan-position of the aircraft is then automatically controlled in relation to the sonar winch cable, with the object of keeping the submersible unit as still and upright as possible in the water. This is achieved by keeping the velocity of the sonar transducer relative to the water near zero. Corrections for the effect of windspeed and water currents, which disturb the cable and submersible unit, can be made using trim controls. Hover height control is maintained as for doppler hover.

2.5 Transition up (Figs 10 and 11)

Before the submersible unit has been winched out of the water, the AFCS doppler mode is re-selected. When the unit is in the trail position or housed and the pilot is ready to break hover, the transition up switch is engaged. The aircraft then climbs out from hover to the altitude set on the set radio height control and to the value of groundspeed at which the set exit speed control has been set. The manoeuvre is programmed to take approximately 80 s.

At the completion of transition up, the aircraft continues to fly at the set radio height and remains stabilized at the flight attitude existing at the completion of transition up. Groundspeed control ceases to operate, but the autostabilizer/autopilot facility remains engaged. The yaw channel functions as a heading hold facility (pilot not moving pedals) or as a yaw damper (pilot moving pedals) throughout the ASW manoeuvre, and also after completion of transition up, unless the autostabilizer/autopilot facility is disengaged.

3. THE AFCS ASW MODE MATMEMATICAL MODEL

3.1 Inertial height smoother (Fig. 2)

The purpose of the inertial height smoother (I.H.S.) is to attenuate any fluctuations of the raw radio altitude signal, E RAD A, obtained from the radio altimeter (for example, those

caused by wave motion on the sea surface). The resultant output signal is termed the smoothed radio altitude, ER SM A. The smoother circuit also provides a vertical velocity signal, V VEL A1. Signals ER SM A, E RAD A and V VEL A1 are used in radio altitude control (Fig. 3).

The I.H.S. circuit, which constitutes part of the amplifier unit in the aircraft system (Fig. 9), receives two input signals:

(i) The vertical acceleration signal, V ACC A1, obtained from the repeater platform unit.
(ii) E RAD A, the raw radio altitude signal.

A change of configuration of the I.H.S. circuit occurs at 1060 ft (323 m) altitude. The change is effected by the switch S LSL. A signal limiting circuit associated with amplifier B detects when signal E RAD A reaches the value equivalent to 1060 ft (EL IH1) and prevents ER SM A from exceeding this value. E RAD A varies linearly with altitude up to 1500 ft (457 m), but the smoothed output ER SM A is required only up to 500 ft (152 m). Limitation of signal ER SM to 1060 ft in amplifier B avoids saturation of amplifier circuits which would otherwise occur with prolonged flight above this altitude.

3.1.1 Functioning below 1060 ft (323 m)

In this configuration, switch S LSL is off and amplifier A integrates the vertical acceleration signal V ACC A1, so that V VEL A1 represents vertical velocity. V VEL A1 is then summed with the raw radio altitude signal (E RAD A) and lagged (amplifier B) to produce the smoothed radio altitude signal, ER SM A. In amplifier C, raw radio altitude is summed with smoothed radio altitude to produce the I.H.S. loop error (V ILE).

In addition, V ILE is summed with the vertical acceleration signal (V ACC A1) in amplifier A. This feedback of loop error signal ensures that the required degree of smoothing is obtained, without an unacceptably long settling time at switch-on. Also, V ILE is fed via an integrator (amplifier D) to the repeater platform unit, so that the integrator output (V INT A), represents the long-term average value of I.H.S. loop error. Summed with the vertical acceleration signal (Z ON M), this error correction signal minimizes long-term errors in the I.H.S. circuit.

3.1.2 Functioning above 1060 ft (323 m)

When the aircraft climbs through 1060 ft, limitation of the smoothed radio altitude signal (ER SM A) occurs in amplifier B as described above. Simultaneously, switch S LSL changes to the 'on' sense to alter the circuit configuration.

Because FR SM A remains constant at altitudes over 1060 ft, the function of amplifier C is now to measure the amount by which the raw radio altitude signal (E RAD A) exceeds ER SM A. Meanwhile, amplifier A functions as a differentiator to obtain an approximation to vertical velocity (V ILE DT). This vertical velocity signal is always available in readiness for descent through 1060 ft.

In addition, the vertical acceleration signal (V ACC A1) is sign reversed in amplifier E and is fed back via amplifier D to the repeater platform unit, so that amplifier D functions as a nulling integrator. This cancels any long-term drift in the acceleration signal. Note that the 'height above 1060 ft' signal, V ILE, is no longer input to amplifier D but is disconnected by switch S LSL in this configuration.

As the aircraft descends through 1060 ft, the 'height above 1060 ft' signal from amplifier C (V ILE) decreases to zero and becomes I.H.S. loop error again. The function of amplifier A simultaneously changes from differentiation of V ILE to integration of the vertical acceleration input V ACC A1; with this change of function, there is little or no change in the value of the vertical velocity signal V VEL A1. At the input of amplifier B, V VEL A1 is lagged with the raw radio altitude signal (E RAD A), so that the smoothed altitude signal (ER SM A) immediately begins to decrease according to the true rate of descent.

3.2 Radio altitude hold and ASW collective channel (Fig. 3)

3.2.1 Radio altitude hold

When radio altitude hold is engaged (switch S RA engaged with switches S TN and S TD disengaged) the collective channel stabilizes the aircraft at the height selected on the pilot's controller (H SET RA); the channel applies collective pitch control through the auxiliary servo

unit (Fig. 9). H SET RA may be changed while radio altitude hold is engaged to alter the controlled altitude of the aircraft.

The circuitry shown in Figure 3, with the exception of the pilot's controller, is contained in the amplifier unit in the aircraft system (Fig. 9). The outputs E HOV A1 and E HOV A2 from Figure 3 are inputs to the AFCS autostabilizer/autopilot mode described in Reference 2. They are internal signals in the amplifier unit as this also contains the autostabilizer/autopilot mode circuitry.

During radio altitude hold conditions, the aircraft is controlled to the datum altitude when the altitude signals from the I.H.S. (E RAD A and ER SM A) exactly balance the height command signal from the set radio height control (H SET RA) at the inputs to the summing amplifier and integrator circuits and the vertical velocity signal E HOV A1 is zero. A proportional plus integral plus velocity damping law is used to achieve this control.

When the set radio height (H SET RA) is changed, the value of the error signal E HOV A2 is also immediately changed. The aircraft then gains or loses altitude until the signal balance stated above is regained. The signal E HOV A1 provides velocity damping to the motion of the aircraft and the integral term is included to remove steady state errors resulting from altitude changes. A detailed explanation of the construction of the system is given below.

The summing amplifier shown in Figure 3 derives a proportional error signal (E PROP A) from three input signals:

(i) The set radio height signal (E SET RA) from the pilot's controller. Note that H TRANS remains constant at value CHA16 in radio altitude hold mode (i.e. before switches S TD and S TN are engaged—see Fig. 4) so that E SET RA is proportional to H SET RA.

(ii) The set hover height signal (E SET HA) output from the pilot's controller. This signal is not effective in radio altitude hold because the hover height signal (H HOVER) is zero (the value of CHA20) prior to S TD and S TN being engaged—see Figure 4.

(iii) The smoothed radio altitude signal (ER SM A) from the inertial height smoother.

The integrator circuit contains the radio altitude hold/ASW mode engagement switch, S RA. This enables the circuit to operate both as an integrator (S RA on) and as a nulling amplifier (S RA off). Nulling feedback is obtained from the combined output of the summing amplifier and integrator. This maintains the combined output (proportional error plus integral error) at zero in readiness for engagement of radio altitude hold by switch S RA.

Signals fed to the integrator are the set radio height (E SET RA), the set hover height (E SET HA), which is zero in this mode, and the raw radio altitude (E RAD A). E SET RA and E SET HA are combined and the resulting height command signal (E MD IA) is fed through an 'aircraft model' lag circuit. The lag characteristic approximates the altitude response of the aircraft, so that the signal fed to the integrator (E MD OA) approximates to 'predicted' altitude. In this way the error signal E ERO A remains small and the integrator maintains its function of correcting long term errors only. The proportional and integral signals are combined at the output of the integrator circuit to form signal E HOV A2.

The velocity damping signal E HOV A1 is simply the velocity output from the I.H.S. (V VEL A1) switched by S RA and multiplied by constant CHA11. Signals E HOV A1 and E HOV A2 are inputs to the AFCS autostabilizer/autopilot mode described in Reference 2.

3.2.2 A.S.W. collective channel

3.2.2.1 Transition down

Prior to a transition down manoeuvre, the aircraft is flown with the autostabilizer and radio altitude hold facilities both on. Before engaging transition down, hover altitude is preselected on the set hover height control, H SET HA. When transition down is engaged the aircraft descends automatically to the pre-selected hover altitude (and at the same time decelerates to zero forward groundspeed—see Section 3.3.1).

Timing and co-ordination of the transition manoeuvre is provided by a pattern of ramps (in the aircraft system these are voltage changes), known as the transition programme (Fig. 4). Before transition down is engaged via switches S TN and S TD, H HOVER (output B) is zero (CHA20) and H TRANS (output A) is at its maximum value, CHA16. H HOVER and H TRANS

are attenuated (Fig. 3) and multiplied by H SET HA and H SET RA (attenuated) respectively in the pilot's controller to form the altitude demand signals E SET HA and E SET RA.

When transition down is engaged, output A begins to decrease and output B begins to increase according to the time-scale shown on Figure 4. At the end of the transition down, output B is at its maximum value (CHA21) and output A is zero (CHA20). The timing for control switches S TD and S TN are also shown on Figure 4. This mechanism enables the aircraft to descend from the set radio height (H SET RA) to the set hover height (H SET HA) in a smooth manner.

The collective channel functions in a similar manner for both radio altitude hold and transition down manoeuvres, except that switch S TN switches the smoothed radio altitude signal (ER SM A) rather than the raw radio altitude signal (E RAD A) to the input of the integrator for the latter (Fig. 3). One height command signal, the proportional error E PROP A, initiates the progressive change of altitude during the transition, while the second (integral) height command signal, E INT A, ensures that no steady state error exists between the commanded and actual hover heights at the completion of the manoeuvre. The vertical velocity signal, E HOV A1 provides damping of aircraft response during the manoeuvre.

3.2.2.2 Doppler hover

Doppler hover conditions become effective at the completion of transition down. Automatic altitude control (radio altitude hold) remains effective during the hover unless switch S RA is disengaged. Altitude is selected on the set hover height control (H SET HA). Output A from the transition unit is now at zero (CHA20) and output B is at CHA21 (equivalent of 70 ft or 21.3 m). The controlled altitude is determined by the proportion of CHA21 picked off by H SET HA in the manner described in Sections 3.2.1 and 3.2.2.1. Otherwise the collective channel operates as described for radio altitude hold.

3.2.2.3 Transition up

When the transition up manoeuvre is commenced following the doppler hover mode, an automatic climb to the pre-selected cruise altitude, H SET RA, is made (and also an acceleration to the pre-selected speed—see Section 3.3.4). To perform this manoeuvre, S TD is disengaged while S TN remains engaged. The controlled altitude changes smoothly from the selected hover altitude (H SET HA) to H SET RA at the completion of transition up. This is determined by the proportion of H TRANS picked off by H SET RA in the pilot's controller. The operation of the system for this manoeuvre is similar to that for the transition down manoeuvre.

3.3 Pitch and roll channels (Figs 7 and 8)

3.3.1 Transition down

As stated in Section 3.2.2, the aircraft is flown with the autostabilizer on, the radio altitude facility engaged and the set hover height pre-selected, prior to performing a transition down manoeuvre. When the transition down switch (S TD) is engaged, the aircraft decelerates to zero forward groundspeed (and at the same time descends automatically to the pre-selected hover altitude).

The circuitry shown in Figures 7 and 8, with the exception of the repeater platform unit, vertical gyro unit, doppler radar, sonar winch installation, hover trim controller, pilot's controller and sonar operator's controller is contained in the amplifier unit in the aircraft system (Figs 10 and 12 to 14). The outputs E HOV P and E HOV R from the rate and amplitude limiter (part of the amplifier unit—Figs 7 and 8) are inputs to the AFCS autostabilizer/autopilot mode described in Reference 2. They are internal signals in the amplifier unit as this also contains the autostabilizer/autopilot mode circuitry. Outputs S FWD H, S AFT H, S STBD H and S PORT H from the beeper selector and timer circuit of the amplifier unit are inputs to the beeper solenoids of the auxiliary servo unit of the flying controls, described in Reference 1. Figures 10 and 12 to 14 also show the link between the amplifier unit and the auxiliary servo unit for the pitch and roll channels.

In similar fashion to the operation of the collective channel, the timing and co-ordination of the transition manoeuvre in forward speed is provided by a pattern of ramps (the transition

programme—Fig. 5). Before transition down is engaged, output C (U TRANS) is at its (constant) maximum value (CHP39); when transition down is engaged (switches S TD and S TN both on), U TRANS begins to decrease according to the time-scale shown on Figure 5, until at the end of the transition down, it is at zero (CHP41).

3.3.1.1 Groundspeed control, fore and aft (Fig. 7)

In the model, the 'raw' doppler fore-aft groundspeed signal (V DOP P) is formed from the fore-aft groundspeed of the aircraft (U HEH) and the velocity of the sea-surface in the same direction (UFCO). Modelling of the pulse characteristic of the doppler radar is not attempted.

In the ground velocity smoother, the raw groundspeed signal (V DOP P) is summed with the fore-aft acceleration signal (V ACC P) from the repeater platform unit, to form the smoothed groundspeed signal (V GVS P). The lag characteristic of the ground velocity smoother ensures that irregularities in the raw signal, such as might arise during certain sea states, do not have a dominant effect on the smoothed signal.

Before transition down engagement, the groundspeed follow-up circuit functions as a variable potentiometer, fed from output 'C' of the transition unit (U TRANS). The input/output ratio of the follow-up circuit is controlled by feedback from the summing amplifier (E ERR 1P). By this means, the speed demand signal (E HTC PS) is made to 'follow' changes in the value of smoothed groundspeed, so that the groundspeed error signal (E ERR 1P) remains near zero in readiness for transition down engagement.

The integrator circuit contains switch S PC which remains de-energized until the pitch and roll cyclic facilities of transition down are engaged, causing the integrator to function as a nulling amplifier. In this configuration, the input to the integrator (E ERR 2P) is disconnected and feedback is obtained from the combined output of the summing amplifier and integrator (E ERR P), thus maintaining the combined output in readiness for the transition down.

When transition down is engaged, switch S PC in the groundspeed follow-up circuit 'freezes' the potentiometer action of the circuit while U TRANS (output 'C' of the transition unit) decreases linearly to zero as described previously. The timing and co-ordination of the speed demand signal (E HTC PS) is determined by U TRANS as shown in Figure 7.

Once formed, signal E HTC PS takes two separate paths. In one path the signal is summed in the summing amplifier with the smoothed groundspeed signal (V GVS P) obtained from the ground velocity smoother. The summing amplifier produces an error signal (E ERR 1P), which is the difference between the demanded and smoothed groundspeeds. E ERR 1P, combined with integrated speed error obtained from the integrator (E INT P), is fed to the rate and amplitude limiter (signal E HP UL). Note that switch S PD, which determines whether doppler or cable mode is engaged, is in the off (or doppler) position.

In the second path, the speed demand signal (E HTC PS) is fed through the aircraft model lag circuit and summed with raw groundspeed (V DOP P) at the input of the integrator circuit. The output from the lag circuit represents 'predicted' groundspeed, according to the known speed characteristics of the aircraft. The integrator circuit avoids steady state errors in groundspeed occurring at the completion of transition down.

With small signals, the rate and amplitude limiter functions as an amplifier. With larger signals, its amplitude-limiting function restricts signal output to EL HP3 (positive) and —EL HP6 (negative), values representing approximately 80% of the authority of the servo valve in the auxiliary servo unit (Ref. 1). Its rate-limiting function restricts the rate of change of signal output (see Section 3.3.3).

The output signal from the rate and amplitude limiter (E HOV P) is an internal signal in the amplifier unit; it is part responsible for the output signal from the amplifier unit. As illustrated in Figure 10, the amplifier unit output signal operates the pitch channel auxiliary servo which causes a cyclic change of blade pitch through the flying controls. At the start of a transition down manoeuvre, the cyclic change of blade pitch causes a nose-up attitude change. The aircraft progressively loses forward groundspeed so that the input signals decrease in value as the speed demand signal decreases.

The beeper selector and timer provides an extension of authority for the ASW pitch demand signal, by actuating the cyclic pitch trim facility in the auxiliary servo unit (Ref. 1). Just before signal E HOV P reaches the amplitude limit (EL HP3), a sensing circuit at the input of the beeper

selector and timer detects the polarity of the signal and pulses are fed to the appropriate beeper (S FWD H or S AFT H). The link between this output from the amplifier unit and the beeper solenoid is shown in Figure 10.

3.3.1.2 Groundspeed control, lateral (Fig. 8)

Lateral groundspeed control is similar to fore and aft groundspeed control except that no transition unit and groundspeed follow-up circuit exist because the lateral velocity demand signal is zero throughout the transition down manoeuvre. Cyclic control of blade pitch angle maintains both raw and smoothed groundspeed signals at zero. If the aircraft enters the transition with some lateral groundspeed, proportional and integral error signals (E ERR 1R and E INT R respectively) are produced; the combined signal (E HR UL), fed through the rate and amplitude limiter circuit, demands a roll attitude change which decreases the speed error signal to zero. The rate and amplitude limiter in the roll channel applies an amplitude limit (EL HR3) equivalent to approximately one half the authority of the servo valve in the auxiliary servo unit.

3.3.2 Doppler hover

As stated in Section 3.2.2.2, doppler hover conditions commence at the termination of transition down. Automatic groundspeed control remains effective in the doppler hover mode unless cyclic facilities are disengaged (switches S PC and S RC off). In the pitch channel, signal connections are as for transition down. Output C from the transition unit (U TRANS) is now zero (CHP41 on Fig. 5). As a result, the speed demand signal from the groundspeed follow-up circuit (E HTC PS) is also zero, and the pitch channel controls the aircraft to maintain zero fore-aft groundspeed. In the roll channel, the speed demand signal is zero throughout transitions and doppler hover. The channel therefore continues to control aircraft roll attitude so as to maintain zero lateral groundspeed.

3.3.3 Cable hover

To initiate the cable hover mode, the sonar submersible unit (S.U.) is lowered into the sea. Cable hover mode is engaged by switching on S PD (Figs 7 and 8) so that the pitch and roll channels provide plan-position control. These control aircraft attitude to hold the aircraft relative to the S.U.

The S.U. operates best when upright, with no motion through the sea. Plan-position control therefore aims to maintain the S.U. in this condition and trim controls enable compensations for surface sea currents and windforce on the cable to be made. Such control requires information about the angle of the cable relative to the aircraft in pitch and roll (THE CH and PHI CH respectively) and aircraft attitude angles in pitch and roll (THE HE and PHI HE respectively). As indicated on Figures 7 and 8, the former, which are termed fork angle signals, are obtained from the sonar winch installation and the latter are obtained from the repeater platform unit.

As shown in the relevant figures, addition of angle signals takes place in the transformer. The resultant signals (E CAB PE and E CAB RE) are proportional to cable angle signals in pitch and roll relative to the vertical.

The cable length repeater is a module which continuously follows-up and attenuates the cable angle signals. The attenuation is least at maximum paid-out cable length; i.e. S.U. at maximum depth. The device also provides a cable length signal (D CABLE) for use in the pilot's controller for wind effect correction. However, its main outputs, the plan displacement errors (E CA GP and E CA GR in pitch and roll respectively), are connected via the low-pass filter to the inputs of the summing amplifier and integrator circuits. With cable hover engaged (S PD on) the pitch and roll channels function as in doppler hover, except that the controlling quantities are now plan displacement errors from cable angle information rather than velocity information from the doppler radar and transition unit.

When a doppler to cable or cable to doppler mode switch is made, switch S DC CH in the rate and amplitude limiter is activated. On changing mode, the rate and amplitude limiter in the respective channel limits the signals E HOV P4 and E HOV R4 to the slow rate of maximum change (EL HP1 and EL HR1). This limits the aircraft to slow rates of attitude change in response to the change in input conditions. After 4 seconds (CHR28), the rate limit automatically returns

to normal (EL HP2 and EL HR2). A flow chart for the rate and amplitude limiter is shown in Figure 6.

The ground velocity smoother has only acceleration inputs (U HEH DT and V HEH DT) in the cable mode, as the velocity inputs (V DOP P and V DOP R) are switched off through S PD. The outputs of the smoother (V GVS P and V GVS R) are summed with the plan displacement signals E PDE P and E PDE R to improve the stability of plan position control.

To counteract the bowing effect of wind on the exposed portion of the cable, the aircraft has to maintain a position ahead of the S.U. The amount of forward displacement depends on wind strength and length of cable exposed. In the absence of sea currents, the requirement is for the cable to be vertical at the sea surface. For windforce correction, the signal E CAB PE is modified by the pitch trim signal (THE CPT) in the sonar operator's controller. In the roll channel there is no correction for windforce as the dunk manoeuvre is conducted heading into wind.

In addition to windforce affecting the positioning of the S.U., the drag on the cable due to surface sea currents may also affect its positioning. Corrections for this condition can be made through the trim inputs THE CPT and PHI CRT in the sonar operator's controller. These inputs alter the value of signals E PDE P and E PDE R to make a controlled adjustment to the plan position of the aircraft.

3.3.4 Transition up

When the transition up manoeuvre is commenced by disengaging switch S TD with switch S TN still engaged, the aircraft accelerates automatically to the pre-selected groundspeed (U SET EX) set on the pilot's controller (and also climbs to the pre-selected cruise altitude—see Section 3.2.2.3). The pitch channel functions as in transition down apart from the operation of the groundspeed follow-up circuit, which is bypassed. The roll channel maintains zero lateral groundspeed throughout the transition up manoeuvre.

3.3.5 Air sea rescue (ASR) role

The auxiliary hover trim facility enables the aircraft to be manoeuvred, from a location remote from the cockpit, with ± 6 kt (3 m/s) groundspeed, in the fore-aft and lateral planes. This facility is a convenient means of enabling the winch operator to control the aircraft during ASR operations. In the model, the facility is implemented using the inputs P HTC and R HTC on the hover trim controller (Figs 7 and 8). The collective channel functions as in doppler hover. For the hover trim facility to be operative (switch S HT engaged), the aircraft must be in the doppler hover condition (switches S PC and S RC both on, with S PD off).

The operation of the control system in this mode is similar to operation in the doppler hover mode, except that additional fore-aft and lateral speed demand signals (E HTC P and E HTC R) are connected to the inputs of the summing amplifier and integrator circuits, bypassing the groundspeed follow-up circuit in the pitch channel. The outputs from the summing amplifier and integrator circuits (signals E HP UL and E HR UL), are fed to the rate and amplitude limiter in the normal way. However, it should be noted that the slow rate (EL HP1 and EL HR1) in the rate and amplitude limiter is selected automatically (switch S DC CH on) when the pilot engages or disengages the auxiliary hover trim facility through switch S HT. This limits the aircraft to safe rates of attitude change in response to change of input conditions. Figure 12 gives an indication of the overall operation of the ASR facility.

4. CONCLUDING REMARKS

A detailed mathematical model of the AFCS ASW mode for the Sea King Mk.50 helicopter has been outlined. This is to be used in conjunction with similarly detailed models of the flying controls and AFCS autostabilizer/autopilot mode to form the complete control systems model. Representations of the elements used in the AFCS of the aircraft have been made including limits and other non-linearities. The amount of detail included in the model makes it useful for analysing problems which may arise in service with the control system of the helicopter.

NOMENCLATURE

CHA1—23	Constants
CHP1—45	
CHR1—28	
CIH1—16	
D CA AT	Pilot's controller output signal (set hover height)
D CABLE	Cable length
E ERO A, E A2	Collective channel integrator circuit input and output signals
E AM P, E AM R	Aircraft model circuit output signals (pitch, roll)
E CAB PE, E CAB RE	Transformer output signals (pitch, roll)
E CAB PH, E CAB RH	Sonar winch output signals (pitch, roll)
E CA GP, E CA GR	Cable length repeater output signals (pitch, roll)
E CA PT, E CA RT	Sonar operator's controller output signals (pitch, roll)
E ERR P, E ERR R	Combined proportional plus integral error signals (pitch, roll)
E ERR 1P, E ERR 1R	Summing amplifier output signals (pitch, roll)
E ERR 2P, E ERR 2R	Integrator circuit input signals (pitch, roll)
E GYRO P, E GYRO R	Vertical gyro output signals (pitch, roll)
E HOV A1	Collective channel vertical velocity signal
E HOV A2	Collective channel proportional plus integral error signal
E HOV P, E HOV R	Rate and amplitude limiter output signals (pitch, roll)
E HOV P1, E HOV R1	Rate and amplitude limiter internal signals (pitch, roll)
E HOV P4, E HOV R4	
E HP DT, E HR DT	
E HP UL, E HR UL	Rate and amplitude limiter input signals (pitch, roll)
E HTC P, E HTC R	Hover trim controller output signals—unswitched (pitch, roll)
E HTC PS, E HTC RS	Hover trim controller output signals—switched (pitch, roll)
E DT P, E DT R, E INT A	Integrator circuit internal signals (pitch, roll, collective)
E INT P, E INT R	Integrator circuit output signals (pitch, roll)
EL HP1—5	Limits
EL HR1—5	
EL IH1	
E MD IA, E MD OA	Collective channel aircraft model input and output signals
E PDE P, E PDE R	Low-pass filter output signals (pitch, roll)
E PROP A	Collective channel proportional signal
E RAD A	Radio altitude (raw) signal
E RA RS	Switched radio altitude raw/smoothed signal

ER SM	I.H.S. amplifier 'B' output signal
ER SM A	Radio altitude (smoothed) signal
ER SM DT	I.H.S. amplifier 'B' internal signal
E SET HA E SET RA	Pilot's controller output signals used in transition and doppler/cable hover manoeuvres
E STR A	Radio altimeter output signal
G	Gravitational acceleration
H HOVER H TRANS	Transition unit height signals used in transition and doppler/cable hover manoeuvres (model only)
H SET HA	Set hover height
H SET RA	Set radio height
P BIAS, R BIAS	Hover trim controller bias signals
PHI CH, THE CH	Cable angle signals with respect to the helicopter (roll, pitch)
PHI CRT, THE CPT	Sonar operator's controller trim angles (roll, pitch)
PHI HE, THE HE	Attitude angles of helicopter (roll, pitch)
P HTC, R HTC	Hover trim controller (trim) angles (pitch, roll)
s	Laplace operator
S AFT H, S FWD H S PORT H, S STBD H	Beeper selector and timer output signals (aft, forward, port, starboard)
S DC CH	Rate and amplitude limiter slow/normal rate switch
S HT	Hover trim controller engagement switches
S LSL	I.H.S. configuration change switch
S MULT P, S MULT R	Multivibrator output signals (pitch, roll)
S NEG P, S POS P S NEG R, S POS R	Beeper selector and timer internal signals (pitch, roll)
S PC, S RC	ASW cyclic facilities engagement switches (pitch, roll)
S PD, S PD DEL	Cable hover engagement switches
S RA	Radio altitude control engagement switch
S TD, S TDD	Switches which are engaged only during transition down and doppler/cable hover manoeuvres
S TN	Switch which is engaged only during transition down, doppler/cable hover and transition up manoeuvres
t, T	Time
TD, TU	Start times for transition down and transition up manoeuvres (model only)
THA1 THP1—8 THR1—8 TIH1	Time constants
T S DC	Rate and amplitude limiter internal time value
UFCO, VFCO	Sea surface velocity (longitudinal, lateral)

U HEH, V HEH	Helicopter velocities with respect to earth (longitudinal, lateral)
U HEH DT, V HEH DT	Helicopter accelerations with respect to earth (longitudinal, lateral)
U SET EX	Set exit speed signal
U TRANS	Transition unit forward velocity signal used in transition and doppler hover manoeuvres (model only)
V ACC A, V ACC A1	Repeater platform unit vertical output signals (switched, unswitched)
V ACC P, V ACC R	Repeater platform unit output signals (pitch, roll)
V ACC PS	Repeater platform unit output signal—switched (roll)
V DA, V ILE DT, V VA	I.H.S. amplifier 'A' internal signals
V DE US1, V DE US2	Pilot's controller output signals—switched (set exit speed)
V DEM UU	Pilot's controller output signal (set exit speed)
V DOP P, V DOP R	Doppler radar output signals (pitch, roll)
V GFU U	Groundspeed follow-up circuit output signal
V GF U2, V GF U4	Groundspeed follow-up circuit internal signals
V GVS P, V GVS R	Ground velocity smoother output signals (pitch, roll)
V HOVER V TRANS	Transition unit height output signals used in transition and doppler/cable hover manoeuvres
V IA DT	I.H.S. amplifier 'E' output signal
V ILE, V IL S	I.H.S. loop error/height above 1060 ft signal—output of amplifier 'C' (unswitched/switched)
V INT A	I.H.S. amplifier 'D' output signal
V TRAN U	Transition unit forward velocity output signal used in transition and doppler hover manoeuvres
V VEL A, V VEL A1	I.H.S. amplifier 'A' output signals (switched, unswitched)
Z ON COS	Radio altimeter sensing signal
Z ON M	Aircraft vertical acceleration

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3.	Packer, T. J.	Wessex helicopter/sonar dynamics study. Initial report. WRE Technical Note SAD 216, January 1969.
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7.	Guy, C. R.	Sea King Mk.50 helicopter/sonar dynamics study. A simplified control systems mathematical model. ARL Report 152, February 1979.
8.	—	A.P. (RAN) 300-1-6 Chapter 70-0. Automatic flight control system—general.
9.	—	A.P. (RAN) 300-1-6 Chapter 70-1. Autostabilizer/autopilot mode.
10.	—	A.P. (RAN) 300-1-6 Chapter 70-2. ASW mode.
11.	—	A.P. (RAN) 300-1-6 Chapter 70-3. Vertical reference and attitude indication.

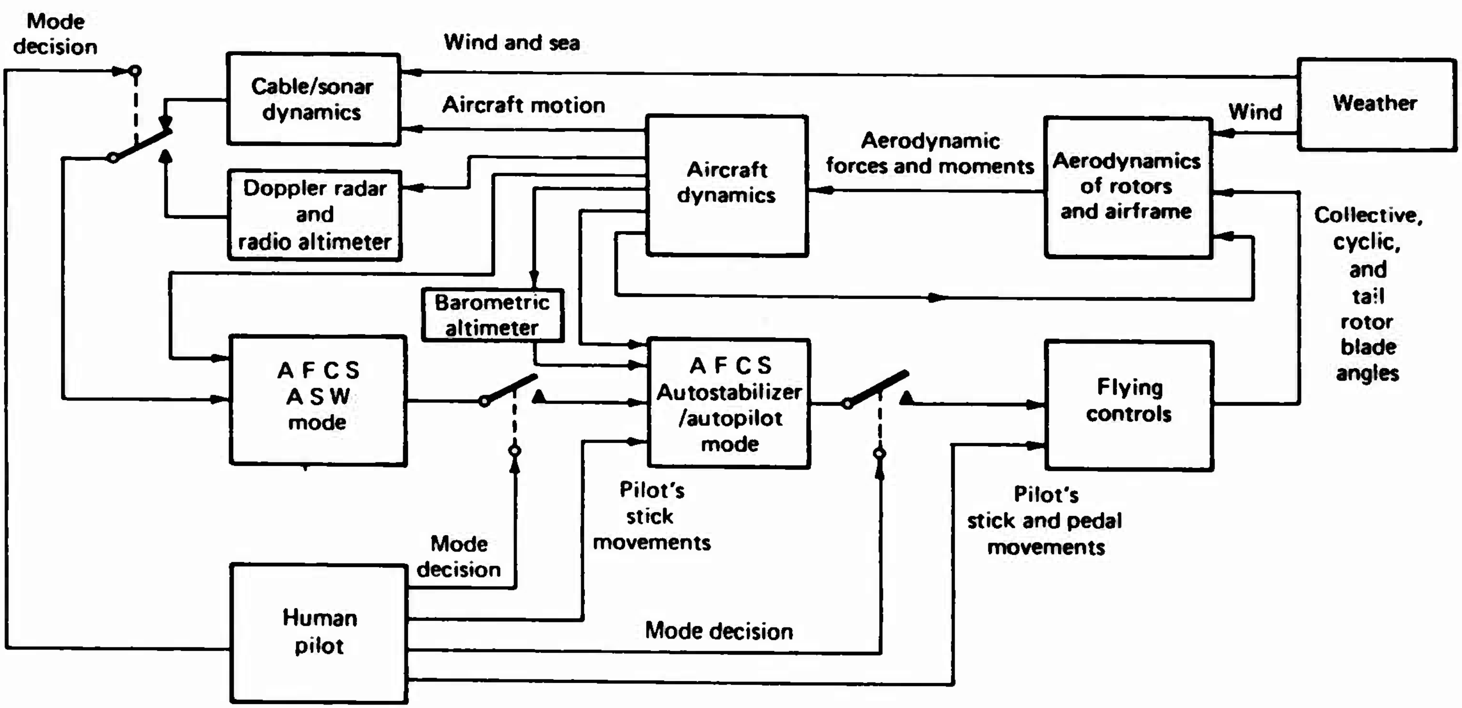


FIG 1. OVERALL BLOCK DIAGRAM FOR THE HELICOPTER/SONAR SYSTEM

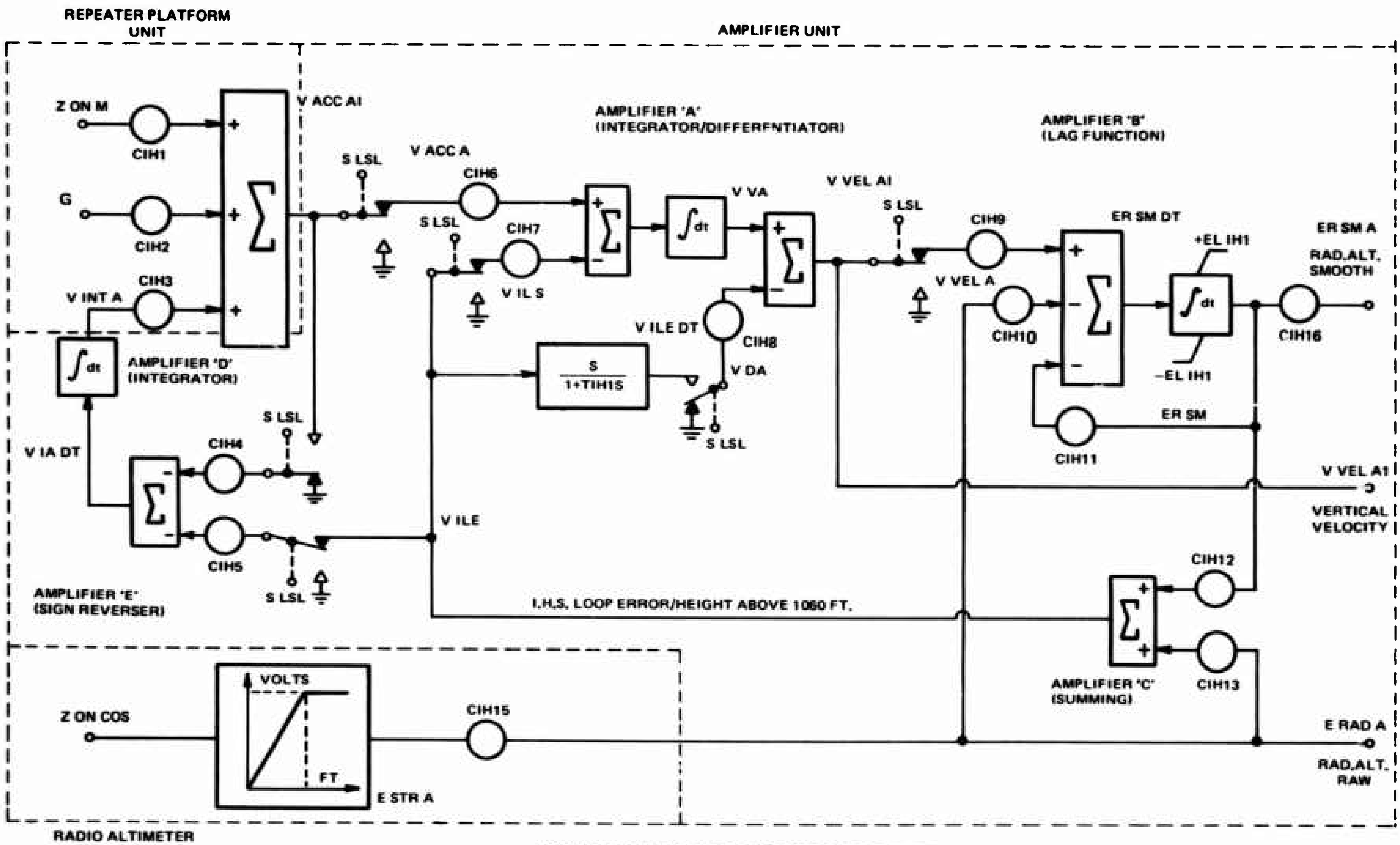


FIGURE 2. INERTIAL HEIGHT SMOOTHER

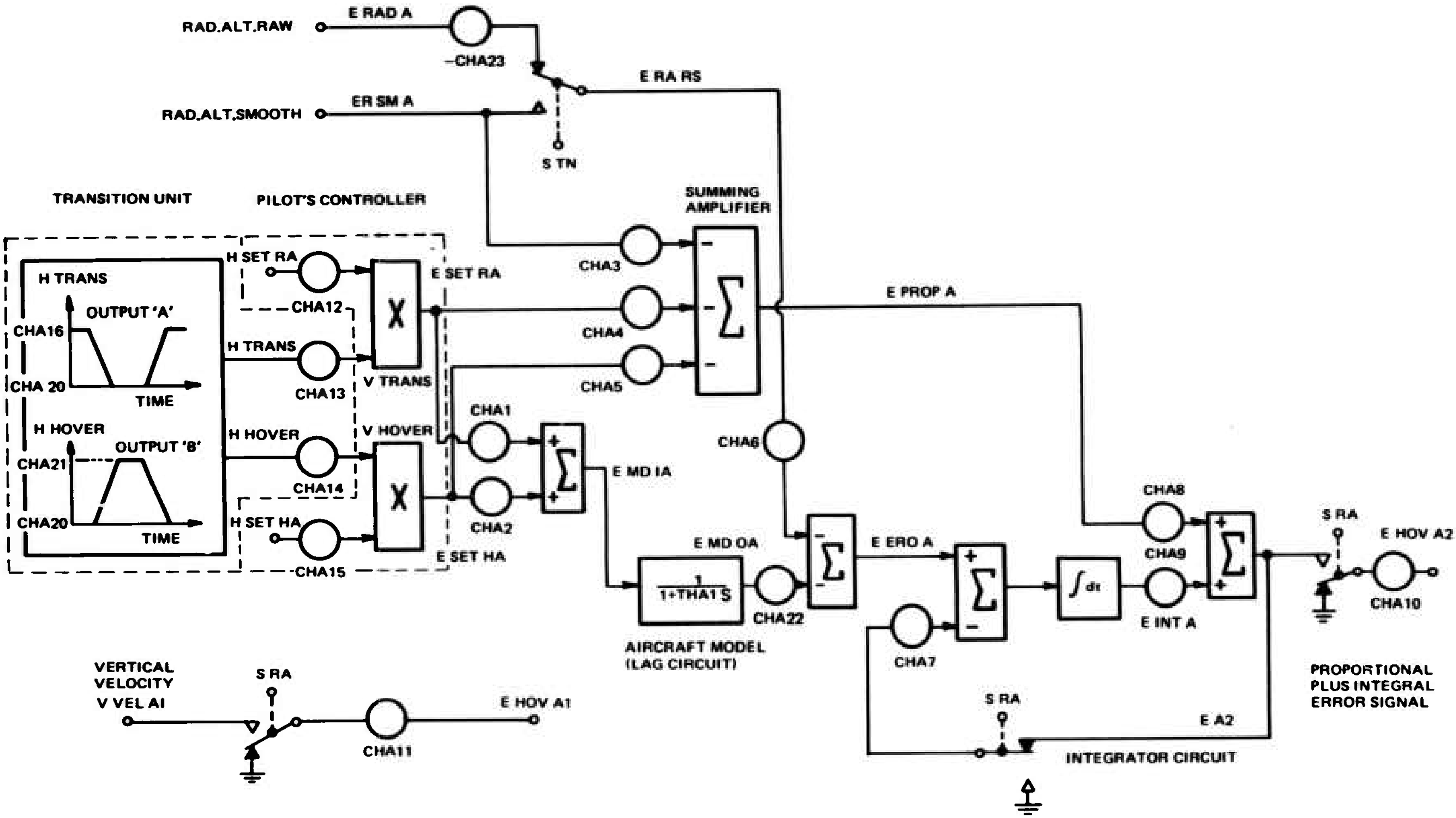


FIGURE 3. RADIO ALTITUDE HOLD AND A S W COLLECTIVE CHANNEL

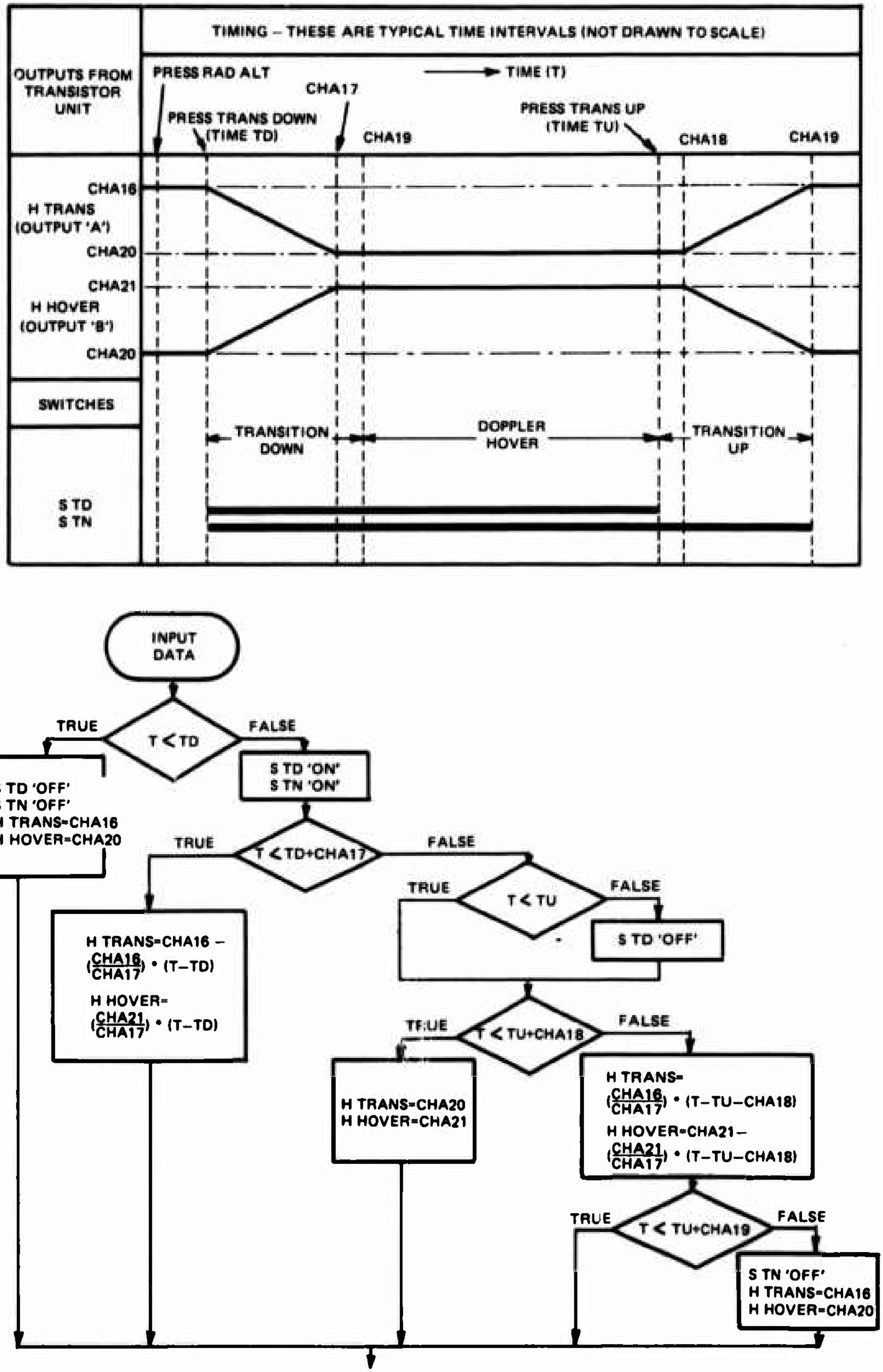


FIGURE 4. TRANSITION UNIT – RAMP TIMING AND FLOW CHART (OUTPUTS 'A' AND 'B')

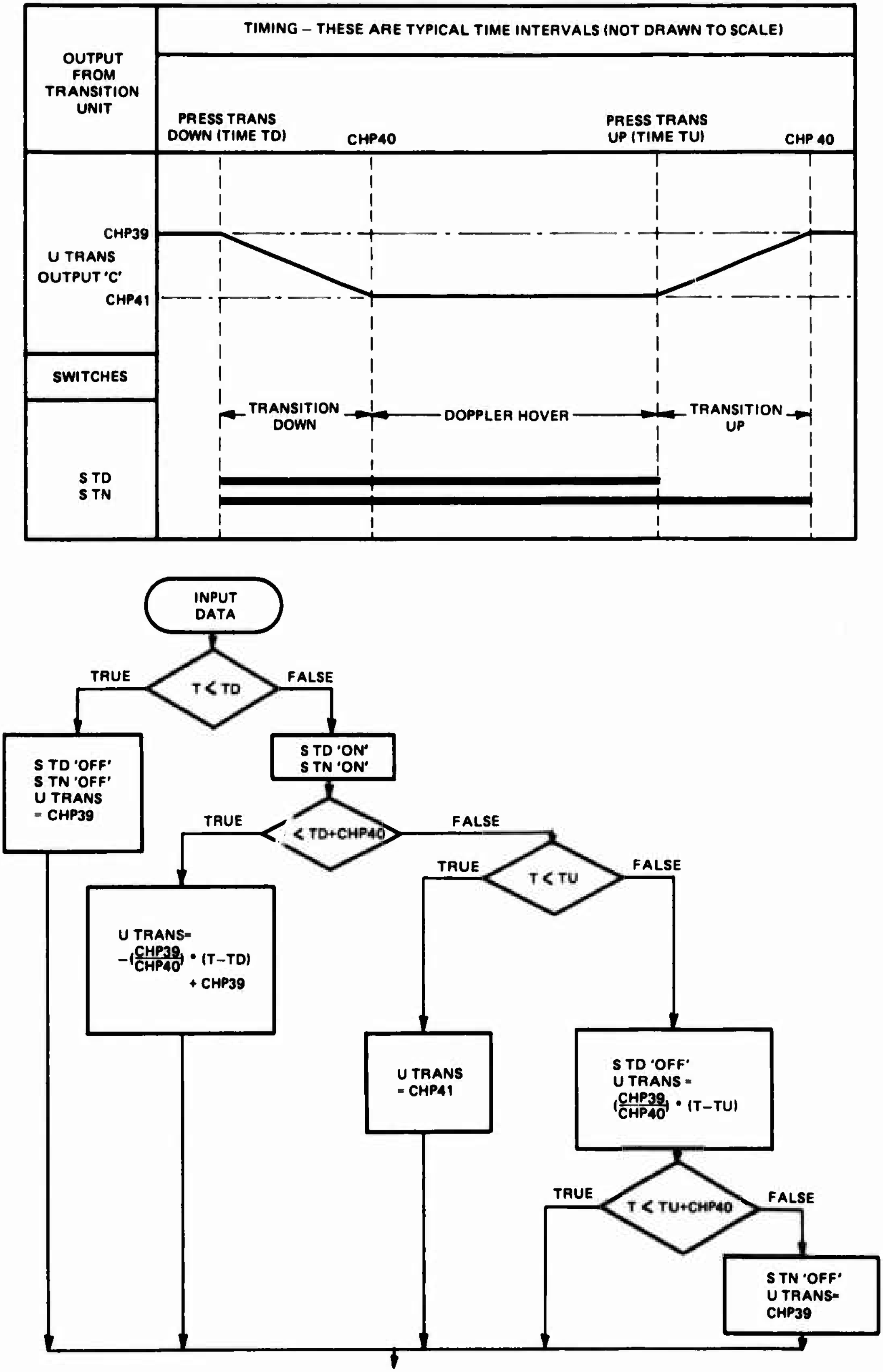


FIGURE 5. TRANSITION UNIT – RAMP TIMING AND FLOW CHART (OUTPUT 'C')

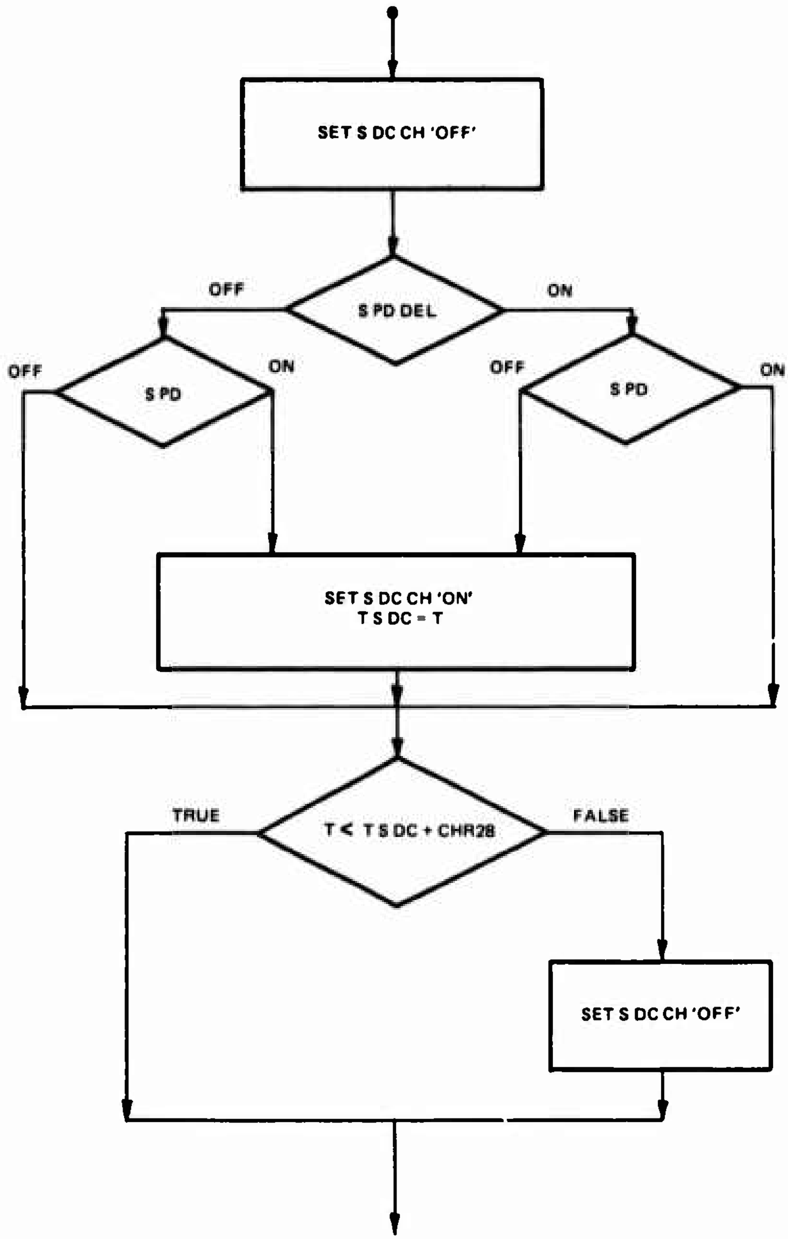
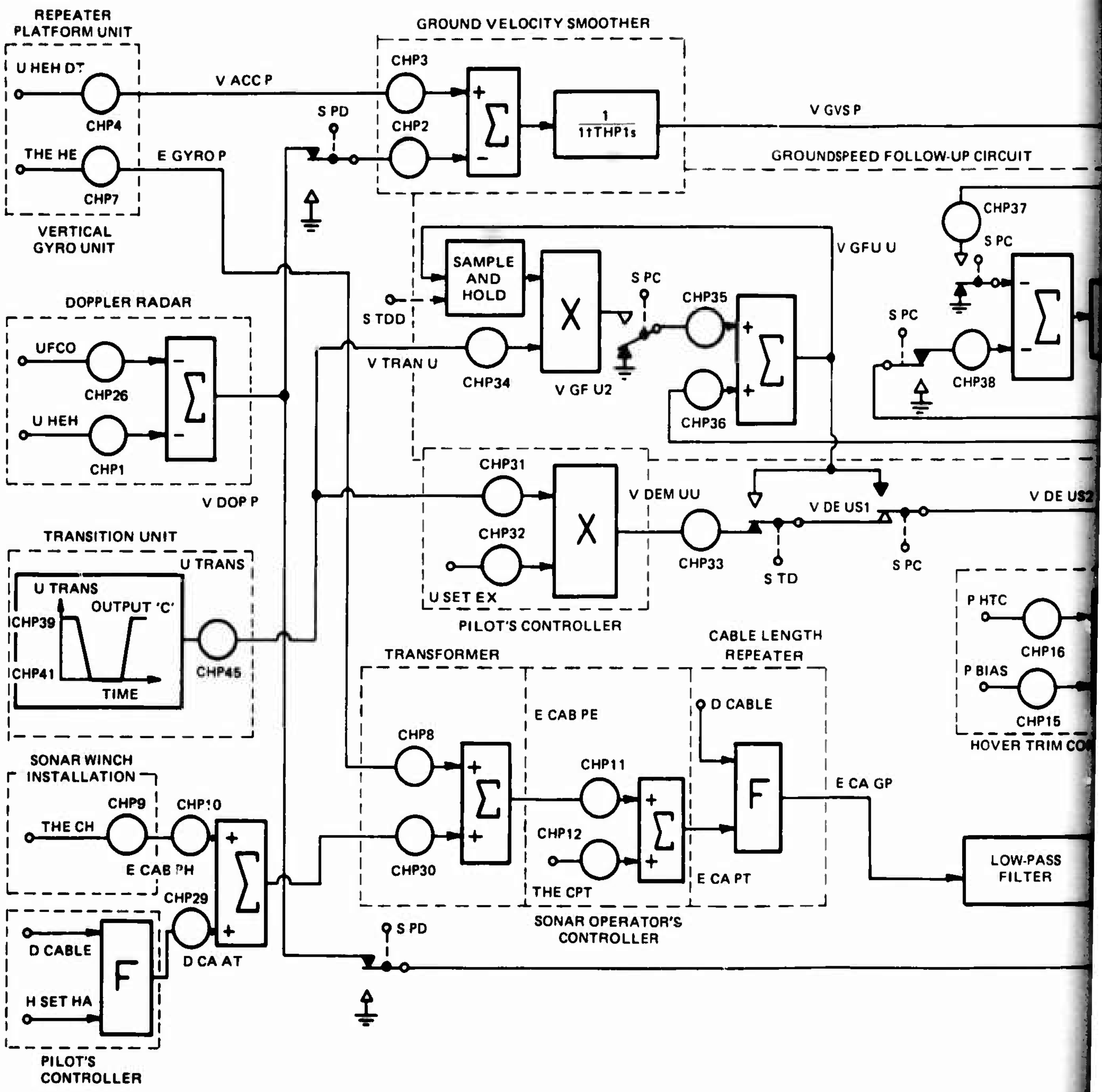


FIGURE 6. RATE AND AMPLITUDE LIMITER – FLOW CHART FOR SLOW RATE SWITCHING



REPEATER PLATFORM UNIT
U HEH DT
CHP4
THE HE
CHP7
VERTICAL GYRO UNIT
V ACC P
E GYRO P
S PD
GROUND VELOCITY SMOOTHER
CHP3
CHP2
1
1†THP1s
V GVS P
GROUNDSPEED FOLLOW-UP CIRCUIT
CHP37
S PC
V GFU U
SAMPLE AND HOLD
S TDD
S PC
CHP35
V TRAN U
CHP34
V GF U2
CHP36
S PC
CHP38
DOPPLER RADAR
UFCO
CHP26
U HEH
CHP1
V DOP P
CHP31
V DEM UU
V DE US1
V DE US2
CHP32
U SET EX
CHP33
S TD
S PC
PILOT'S CONTROLLER
TRANSITION UNIT
U TRANS
U TRANS
OUTPUT 'C'
CHP39
CHP41
TIME
CHP45
P HTC
CHP16
P BIAS
CHP15
HOVER TRIM CO
TRANSFORMER
CABLE LENGTH REPEATER
E CAB PE
D CABLE
CHP8
CHP11
E CA GP
SONAR WINCH INSTALLATION
CHP9
CHP10
THE CH
E CAB PH
CHP30
CHP12
THE CPT
E CA PT
LOW-PASS FILTER
CHP29
D CABLE
D CA AT
H SET HA
S PD
SONAR OPERATOR'S CONTROLLER
PILOT'S CONTROLLER

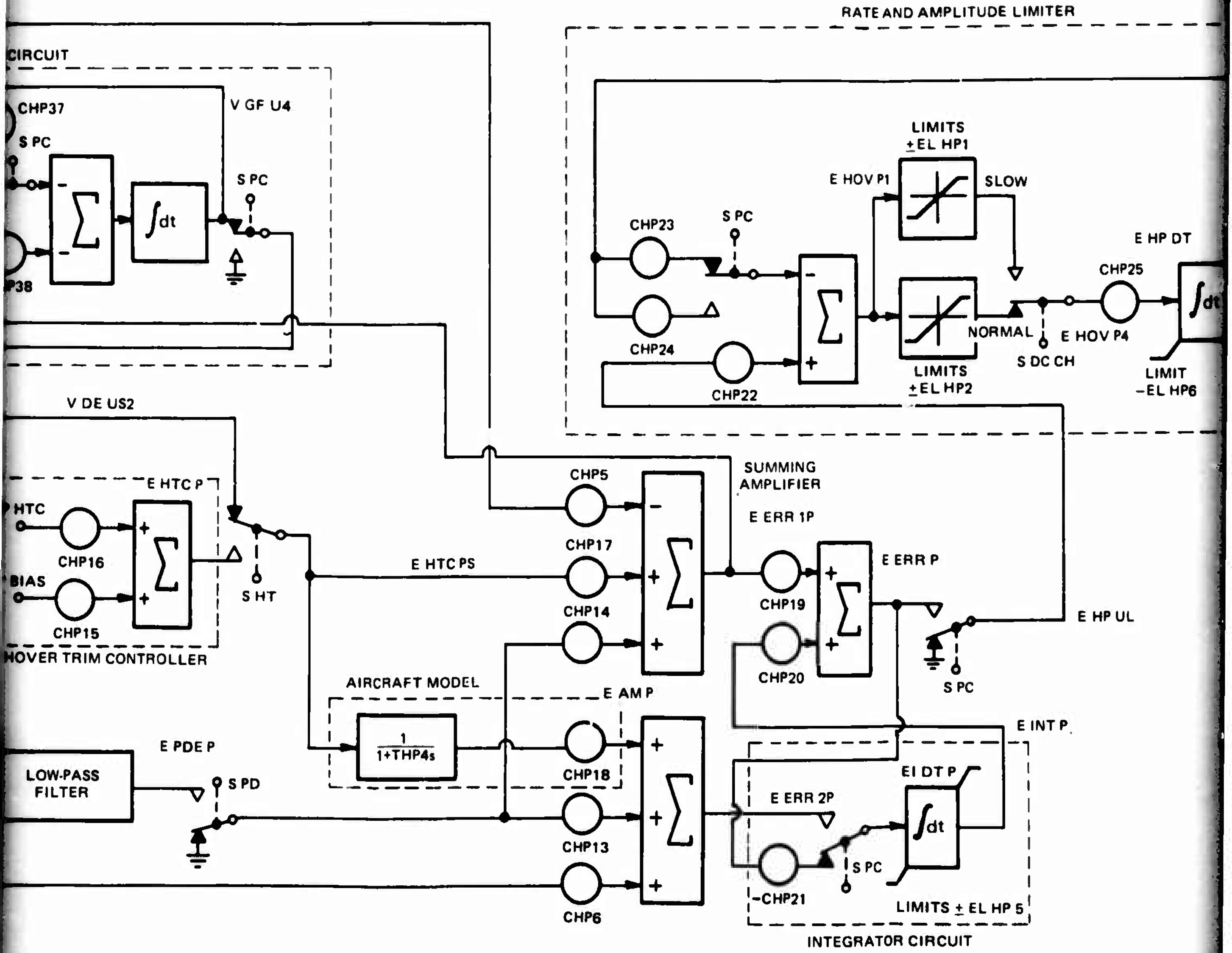
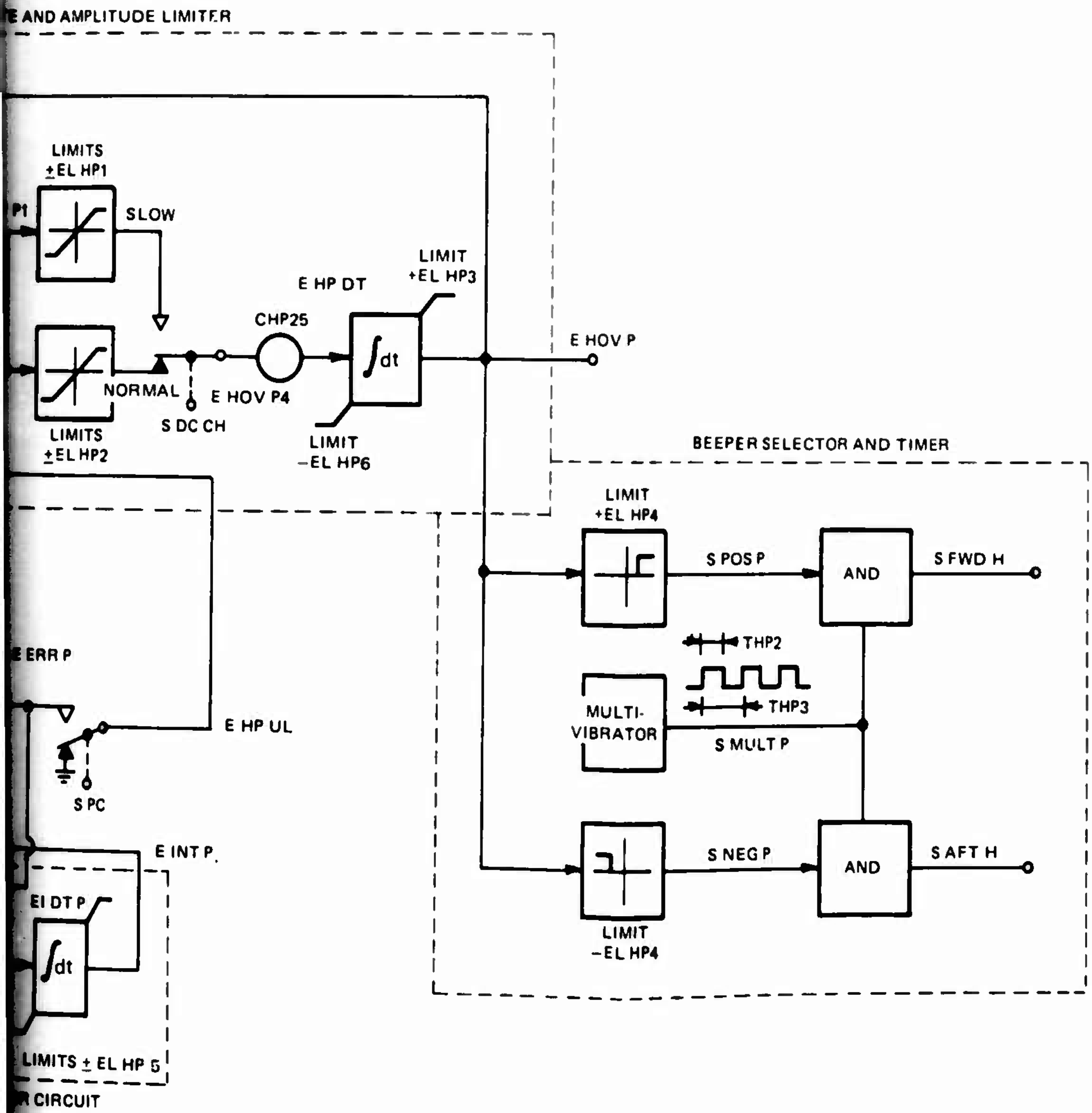
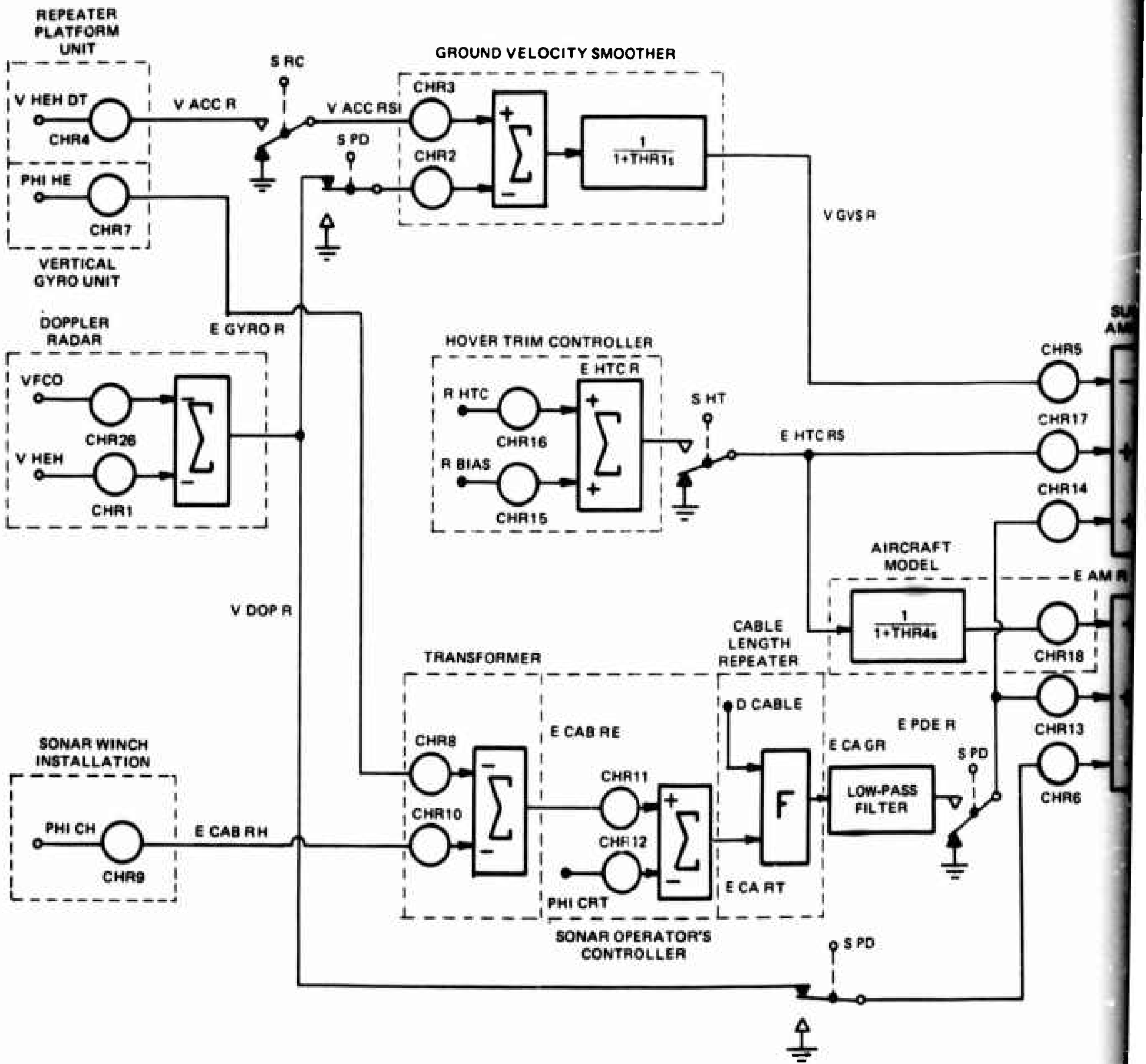
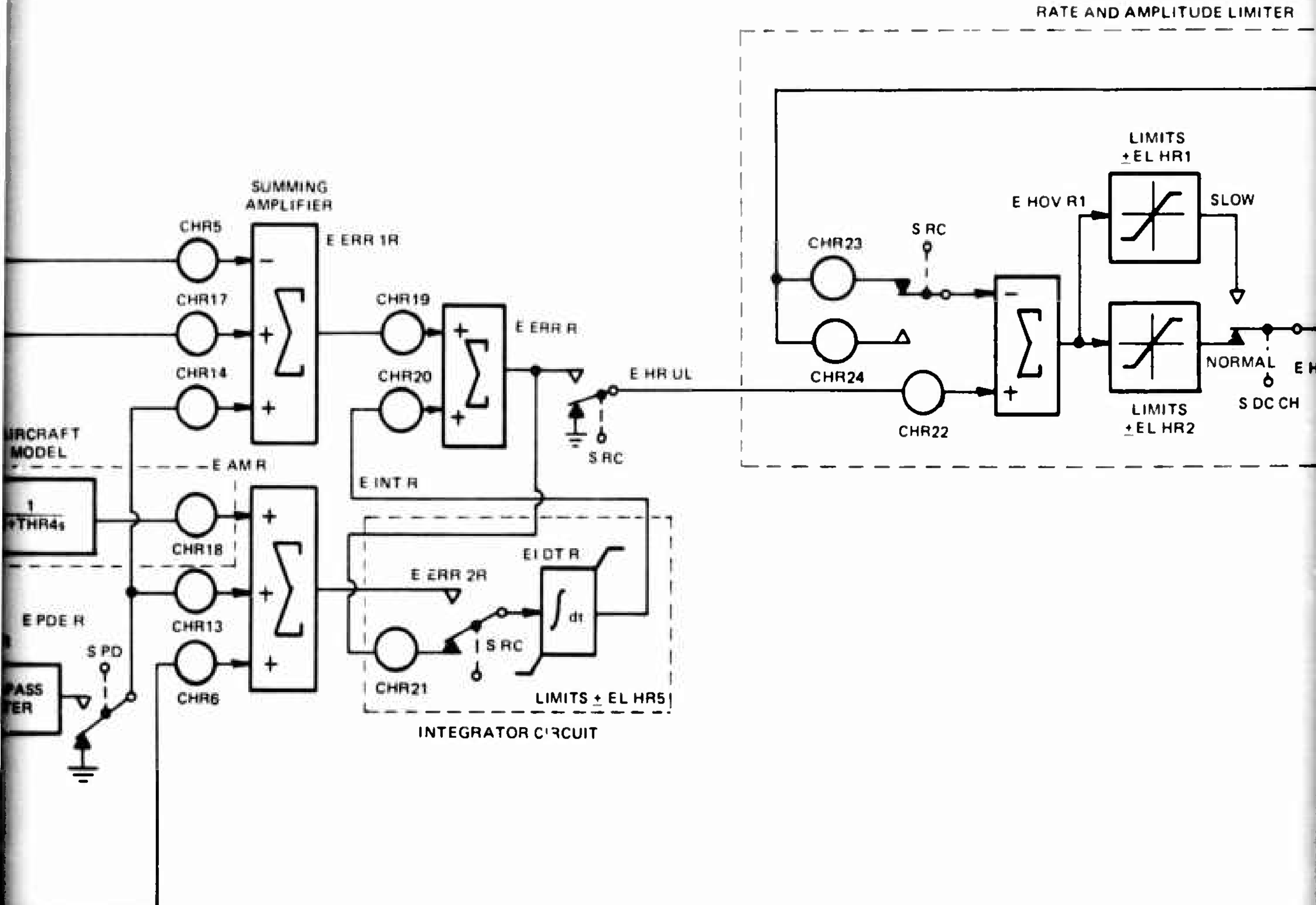


FIGURE 7. A S W MODE PITCH CHANNEL


E AND AMPLITUDE LIMITER
LIMITS
±EL HP1
P1
SLOW
E HP DT
LIMIT
+EL HP3
CHP25
∫dt
E HOV P
NORMAL
E HOV P4
S DC CH
LIMITS
±EL HP2
LIMIT
−EL HP6
BEEPER SELECTOR AND TIMER
LIMIT
+EL HP4
S POS P
AND
S FWD H
THP2
MULTI-
VIBRATOR
THP3
S MULT P
E ERR P
E HP UL
S PC
E INT P
EI DT P
∫dt
LIMITS ± EL HP 5
R CIRCUIT
S NEG P
AND
S AFT H
LIMIT
−EL HP4

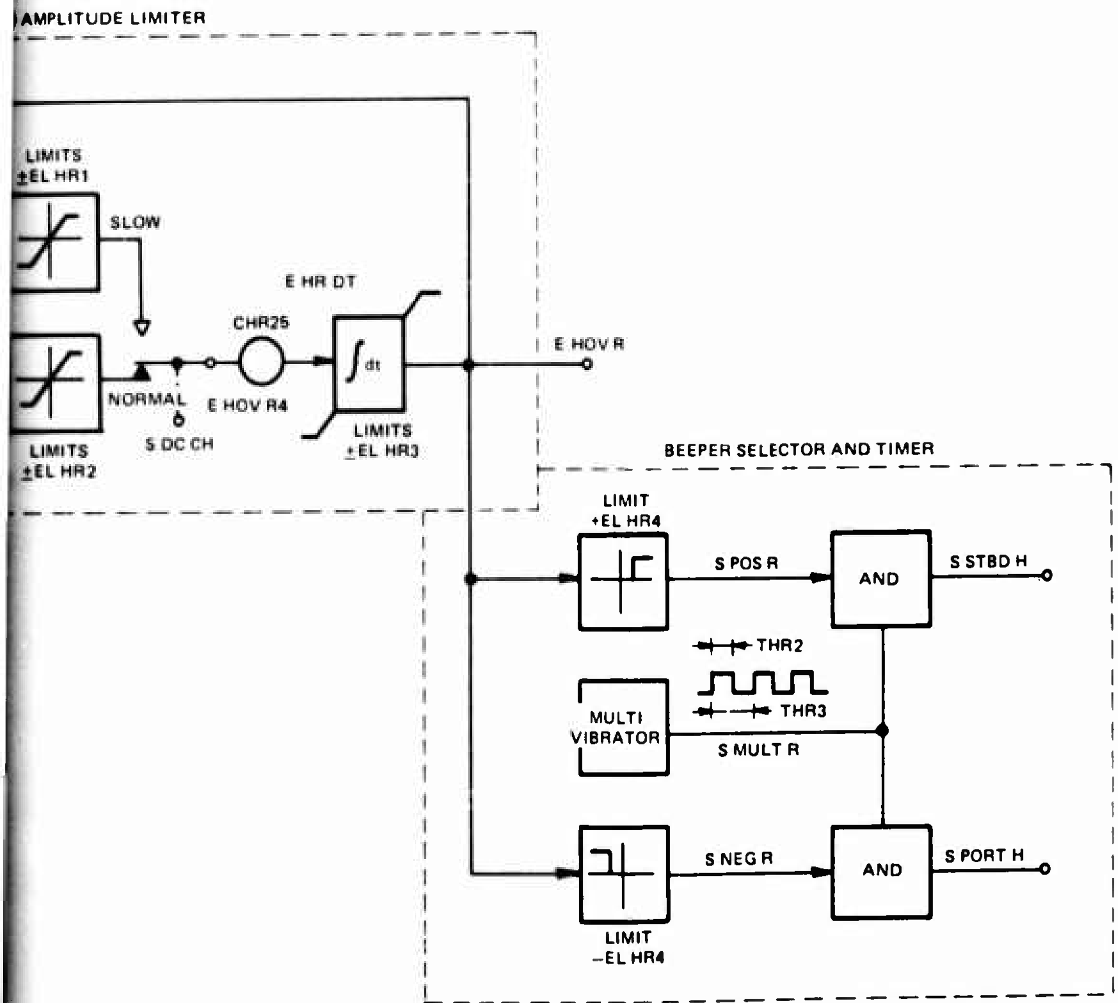


REPEATER PLATFORM UNIT
V HEH DT
CHR4
V ACC R
S RC
V ACC RSI
GROUND VELOCITY SMOOTHER
CHR3
CHR2
S PD
1/(1+THR1s)
PHI HE
CHR7
VERTICAL GYRO UNIT
V GVS R
DOPPLER RADAR
E GYRO R
VFCO
CHR26
V HEH
CHR1
HOVER TRIM CONTROLLER
E HTC R
R HTC
CHR16
R BIAS
CHR15
S HT
E HTC RS
CHR5
CHR17
CHR14
AIRCRAFT MODEL
E AM R
1/(1+THR4s)
CHR18
V DOP R
TRANSFORMER
CABLE LENGTH REPEATER
D CABLE
E CAB RE
E PDE R
CHR8
CHR13
E CA GR
S PD
CHR11
LOW-PASS FILTER
CHR10
CHR6
CHR12
F
SONAR WINCH INSTALLATION
PHI CH
CHR9
E CAB RH
E CA RT
PHI CRT
SONAR OPERATOR'S CONTROLLER
S PD



2

FIGURE 8. A S W MODE ROLL CHANNEL


AMPLITUDE LIMITER
LIMITS
±EL HR1
SLOW
E HR DT
CHR25
E HOV R
NORMAL
E HOV R4
S DC CH
LIMITS
±EL HR2
LIMITS
±EL HR3
BEEPER SELECTOR AND TIMER
LIMIT
+EL HR4
S POS R
AND
S STBD H
THR2
MULTI
VIBRATOR
THR3
S MULT R
S NEG R
AND
S PORT H
LIMIT
−EL HR4

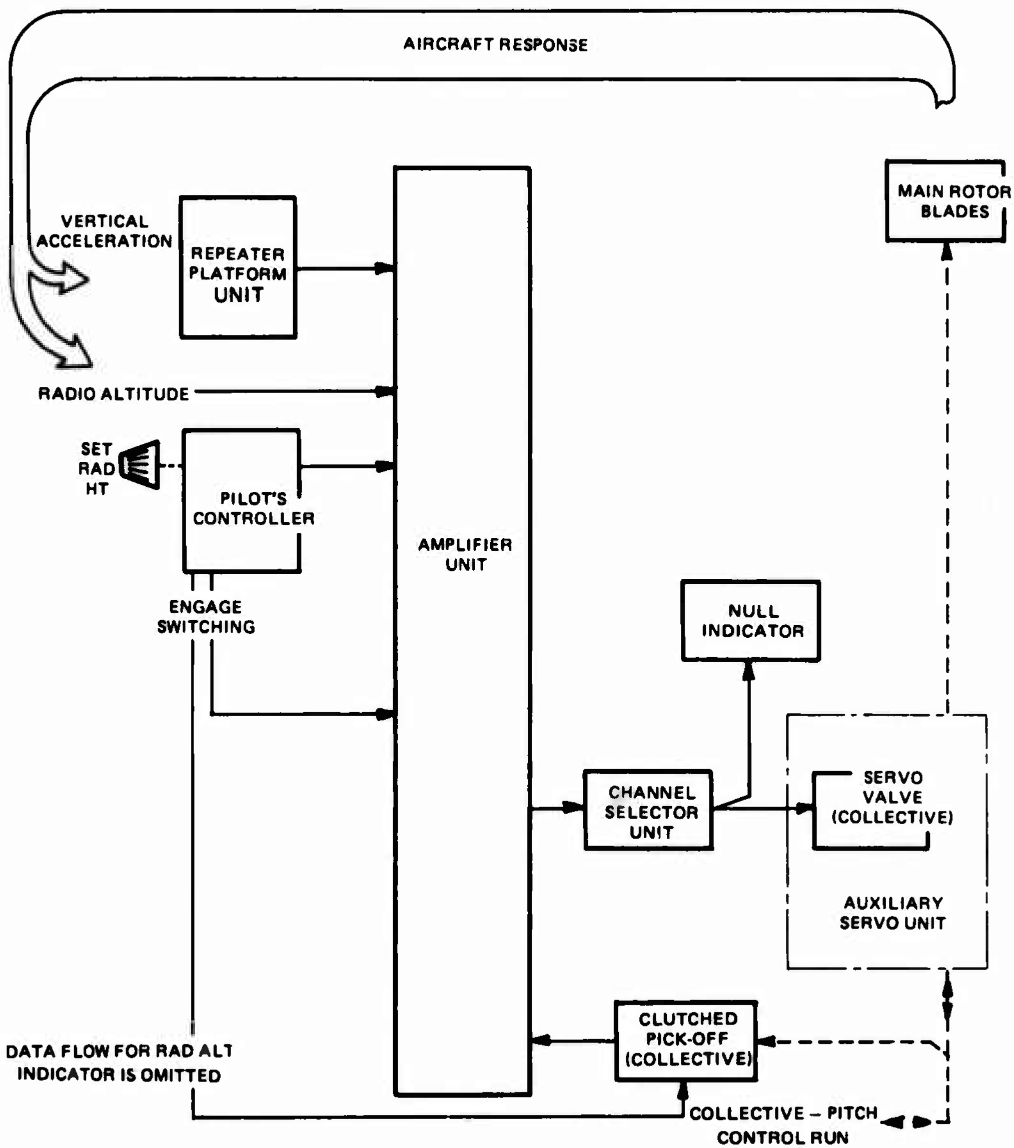


FIGURE 9. RADIO ALTITUDE HOLD (TAKEN FROM REF 8)

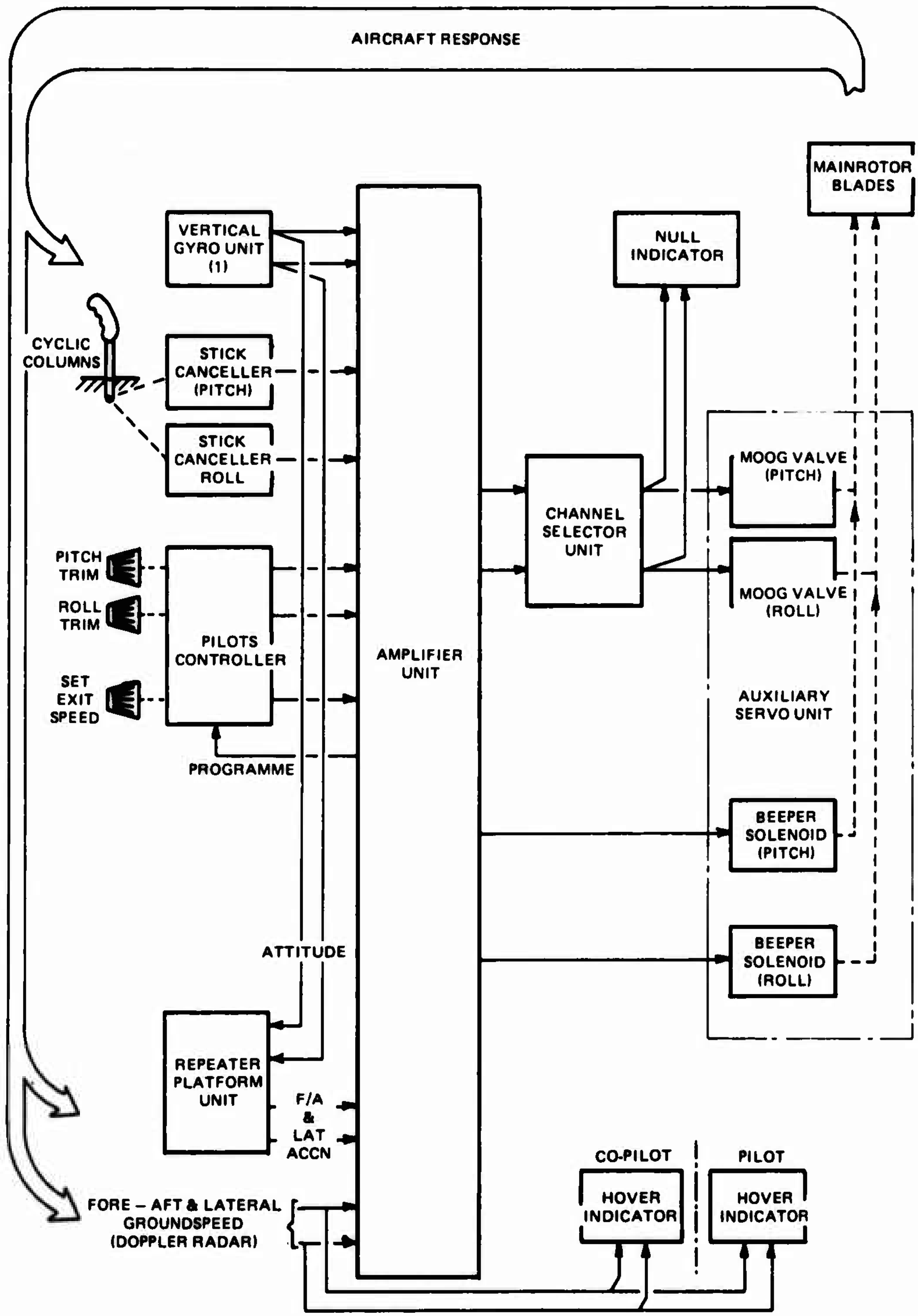


FIGURE 10. TRANSITIONS AND DOPPLER HOVER, PITCH AND ROLL CHANNELS (TAKEN FROM REF 8)

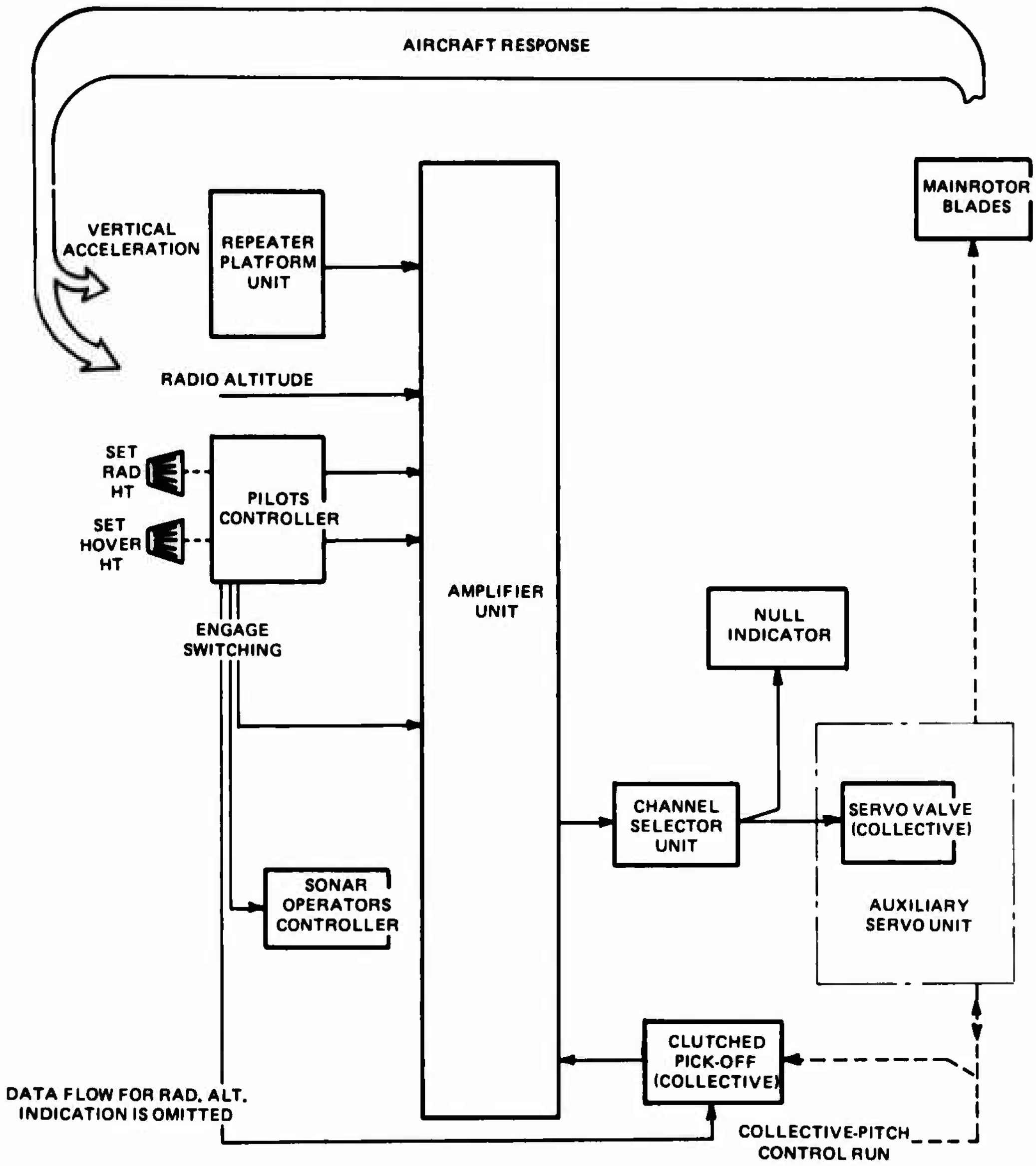


FIGURE 11. TRANSITIONS AND DOPPLER HOVER, COLLECTIVE CHANNEL (TAKEN FROM REF 8)

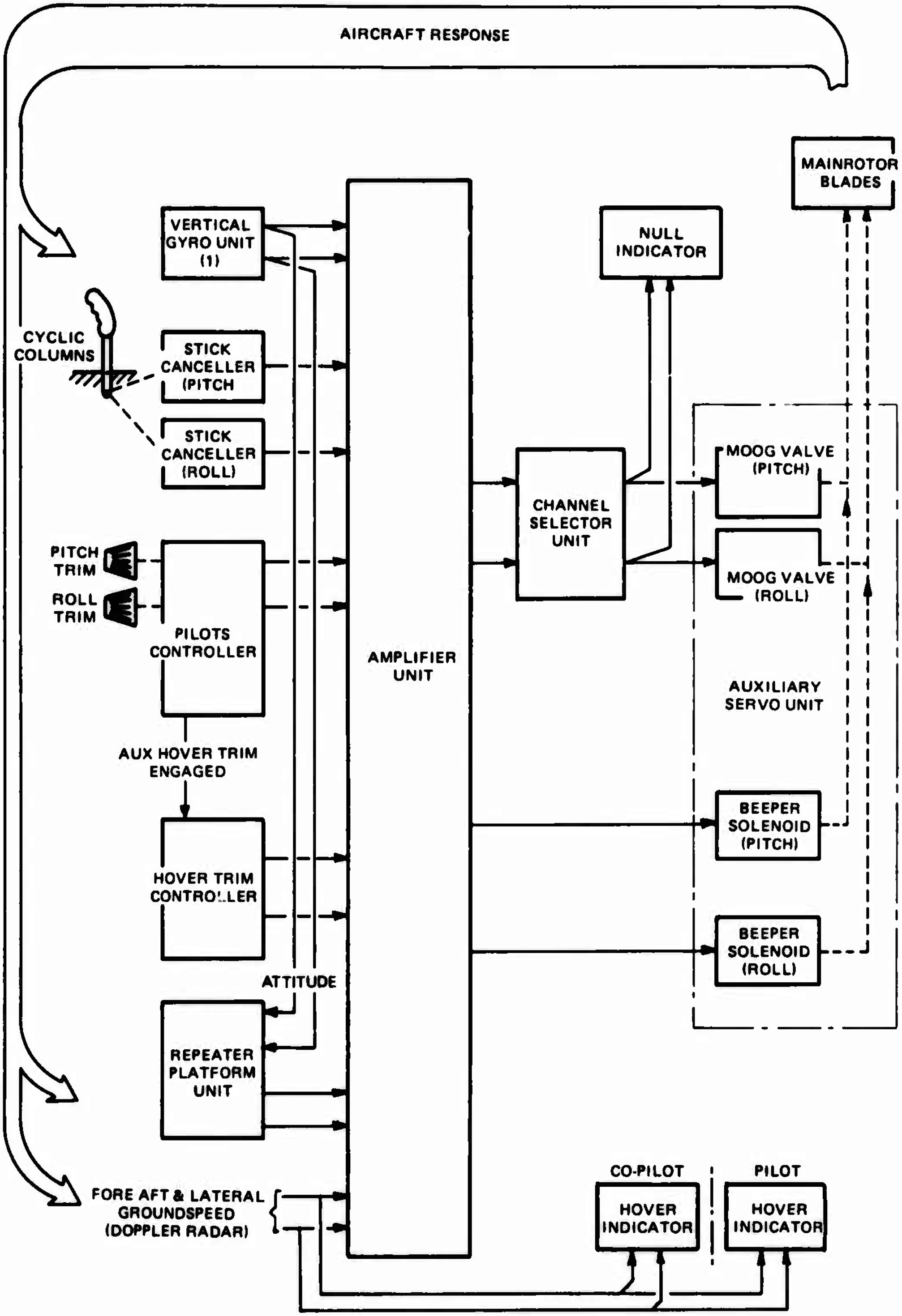


FIGURE 12. A S R FACILITY (TAKEN FROM REF 8)

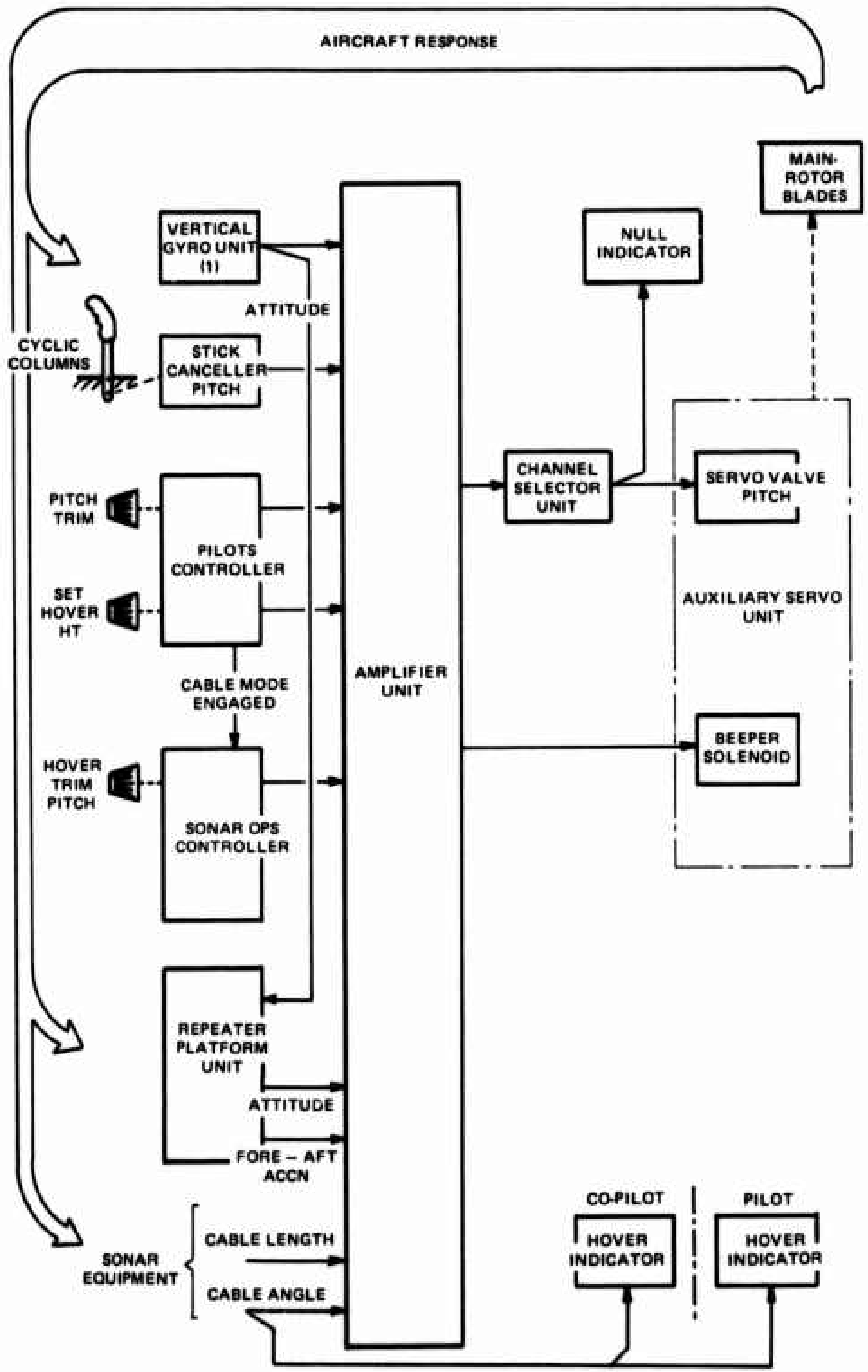


FIGURE 13. CABLE HOVER, PITCH CHANNEL (TAKEN FROM REF 8)

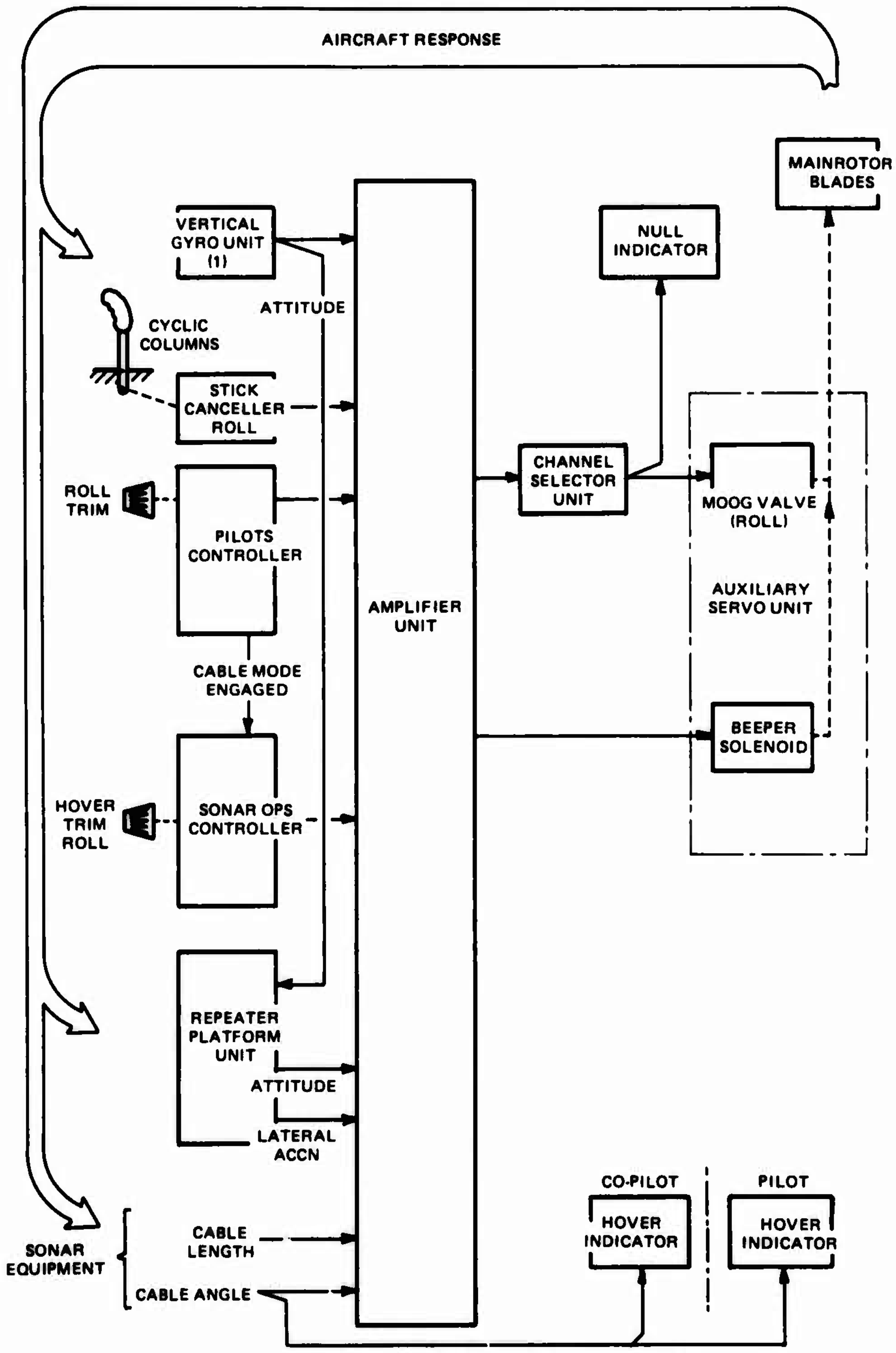


FIGURE 14. CABLE HOVER, ROLL CHANNEL (TAKEN FROM REF 8)

APPENDIX I

EQUATIONS FOR THE AFCS ASW MODE MATHEMATICAL MODEL

1. Inertial Height Smoother (Fig. 2)

1.1 Radio altimeter

$$\text{E STR A} = \text{Function (Z ON COS)} \tag{1.1}$$

$$\text{E RAD A} = \text{CIH15} * \text{E STR A} \tag{1.2}$$

1.2 Repeater platform unit

$$\text{V ACC A1} = \text{CIH1} * \text{Z ON M} + \text{CIH2} * \text{G} + \text{CIH3} * \text{V INT A} \tag{1.3}$$

1.3 Amplifier unit

1.3.1 Amplifier 'A' (integrator/differentiator)

$$\left.\begin{array}{l}\text{If S LSL is on}\\ \text{V ACC A} = 0\\ \text{V IL S} = 0 \text{ and}\\ \text{V DA} = \text{V ILE DT}\end{array}\right\} \tag{1.4}$$

$$\left.\begin{array}{l}\text{If S LSL is off}\\ \text{V ACC A} = \text{V ACC A1}\\ \text{V IL S} = \text{V ILE and}\\ \text{V DA} = 0\end{array}\right\} \tag{1.5}$$

$$\text{V ILE DT} = \left(\frac{s}{1 + \text{TIH1}s}\right) * \text{V ILE} \tag{1.6}$$

$$\left.\begin{array}{l}\text{V VA} = \int(\text{CIH6} * \text{V ACC A} - \text{CIH7} * \text{V IL S})\,dt + \text{V VA}_{t=0}\\ \text{where V VA}_{t=0} \text{ is the initial condition of V VA}\end{array}\right\} \tag{1.7}$$

$$\text{V VEL A1} = \text{V VA} + \text{CIH8} * \text{V DA} \tag{1.8}$$

1.3.2 Amplifier 'B' (lag function)

$$\left.\begin{array}{l}\text{If S LSL is on}\\ \text{V VEL A} = 0\end{array}\right\} \tag{1.9}$$

$$\left.\begin{array}{l}\text{If S LSL is off}\\ \text{V VEL A} = \text{V VEL A1}\end{array}\right\} \tag{1.10}$$

$$\text{ER SM DT} = \text{CIH9} * \text{V VEL A} - \text{CIH10} * \text{E RAD A} - \text{CIH11} * \text{ER SM} \tag{1.11}$$

$$\text{ER SM} = \int(\text{ER SM DT})\,dt + \text{ER SM}_{t=0} \tag{1.12}$$

$$\left.\begin{array}{l}\text{If } |\text{ER SM}| < |\text{EL IH1}|\\ \text{ER SM} = \text{ER SM}\end{array}\right\} \tag{1.13}$$

$$\left.\begin{array}{l}\text{If } |\text{ER SM}| \geqslant |\text{EL IH1}|\\ \text{ER SM} = |\text{EL IH1}| * \text{SIGN (ER SM DT)}\end{array}\right\} \tag{1.14}$$

$$\text{ER SM A} = \text{CIH16} * \text{ER SM} \tag{1.15}$$

1.3.3 Amplifier 'C' (summing)

$$V\ ILE = CIH12 * ER\ SM + CIH13 * E\ RAD\ A \tag{1.16}$$

1.3.4 Amplifier 'D' (integrator)

$$V\ INT\ A = \int (V\ IA\ DT)\, dt + V\ INT\ A_{t=0} \tag{1.17}$$

1.3.5 Amplifier 'E' (sign reverser)

$$\left.\begin{array}{l}\text{If S LSL is on}\\ V\ IA\ DT = -CIH4 * V\ ACC\ A1\end{array}\right\} \tag{1.18}$$

$$\left.\begin{array}{l}\text{If S LSL is off}\\ V\ IA\ DT = -CIH5 * V\ ILE\end{array}\right\} \tag{1.19}$$

2. Radio Altitude hold and ASW Collective Channel (Fig. 3)

2.1 Vertical velocity signal

$$\left.\begin{array}{l}\text{If S RA is on}\\ E\ HOV\ A1 = CHA11 * V\ VEL\ A1\end{array}\right\} \tag{2.1}$$

$$\left.\begin{array}{l}\text{If S RA is off}\\ E\ HOV\ A1 = 0\end{array}\right\} \tag{2.2}$$

2.2 Transition unit

$$H\ TRANS = \text{Function } (t, S\ TD, S\ TN) \text{ (see Fig. 4)} \tag{2.3}$$

$$V\ TRANS = CHA13 * H\ TRANS \tag{2.4}$$

$$H\ HOVER = \text{Function } (t, S\ TD, S\ TN) \text{ (see Fig. 4)} \tag{2.5}$$

$$V\ HOVER = CHA14 * H\ HOVER \tag{2.6}$$

2.3 Pilot's controller

$$E\ SET\ RA = CHA12 * H\ SET\ RA * V\ TRANS \tag{2.7}$$

$$E\ SET\ HA = CHA15 * H\ SET\ HA * V\ HOVER \tag{2.8}$$

2.4 Aircraft model (lag circuit)

$$E\ MD\ IA = (CHA1 * E\ SET\ RA) + (CHA2 * E\ SET\ HA) \tag{2.9}$$

$$E\ MD\ OA = \left(\frac{1}{1 + THA1s}\right) * E\ MD\ IA + E\ MD\ OA_{t=0} \tag{2.10}$$

2.5 Integrator circuit

$$\left.\begin{array}{l}\text{If S TN is on}\\ E\ RA\ RS = ER\ SM\ A\end{array}\right\} \tag{2.11}$$

$$\left.\begin{array}{l}\text{If S TN is off}\\ E\ RA\ RS = -CHA23 * E\ RAD\ A\end{array}\right\} \tag{2.12}$$

$$E\ ERO\ A = -(CHA22 * E\ MD\ OA) - (CHA6 * E\ RA\ RS) \tag{2.13}$$

$$\left.\begin{array}{l}\text{If S RA is on}\\ E\ INT\ A = \int (E\ ERO\ A)\, dt + E\ INT\ A_{t=0}\end{array}\right\} \tag{2.14}$$

$$\left.\begin{array}{l}\text{If S RA is off}\\ E\ INT\ A = \int (E\ ERO\ A - (CHA7 * E\ A2))\, dt + E\ INT\ A_{t=0}\end{array}\right\} \tag{2.15}$$

2.6 Proportional plus integral error signal

$$\left.\begin{aligned} \text{E PROP A} = -(\text{CHA3} * \text{ER SM A}) - (\text{CHA4} * \text{E SET RA}) \\ - (\text{CHA5} * \text{E SET HA}) \end{aligned}\right\} \quad (2.16)$$

$$\text{E A2} = (\text{CHA8} * \text{E PROP A}) + (\text{CHA9} * \text{E INT A}) \quad (2.17)$$

$$\left.\begin{aligned} &\text{If S RA is on} \\ &\text{E HOV A2} = \text{CHA10} * \text{E A2} \end{aligned}\right\} \quad (2.18)$$

$$\left.\begin{aligned} &\text{If S RA is off} \\ &\text{E HOV A2} = 0 \end{aligned}\right\} \quad (2.19)$$

3. ASW Mode Pitch Channel (Fig. 7)

3.1 Repeater platform unit

$$\text{V ACC P} = \text{CHP4} * \text{U HEH DT} \quad (3.1)$$

3.2 Vertical gyro unit

$$\text{E GYRO P} = \text{CHP7} * \text{THE HE} \quad (3.2)$$

3.3 Doppler radar

$$\text{V DOP P} = -(\text{CHP26} * \text{UFCO}) - (\text{CHP1} * \text{U HEH}) \quad (3.3)$$

3.4 Transition unit

$$\text{U TRANS} = \text{Function (t, S TD, S TN) (see Fig. 5)} \quad (3.4)$$

$$\text{V TRAN U} = \text{CHP45} * \text{U TRANS} \quad (3.5)$$

3.5 Sonar winch installation

$$\text{E CAB PH} = \text{CHP9} * \text{THE CH} \quad (3.6)$$

3.6 Pilot's controller

$$\text{D CA AT} = \text{Function (D CABLE, H SET HA)} \quad (3.7)$$

$$\text{V DEM UU} = \text{CHP31} * \text{V TRAN U} * \text{CHP32} * \text{U SET EX} \quad (3.8)$$

3.7 Ground velocity smoother

$$\left.\begin{aligned} &\text{If S PD is on} \\ &\text{V GVS P} = \text{CHP3} * \text{V ACC P} * \left(\frac{1}{1 + \text{THP1s}}\right) + \text{V GVS P}_{t=0} \end{aligned}\right\} \quad (3.9)$$

$$\left.\begin{aligned} &\text{If S PD is off} \\ &\text{V GVS P} = (\text{CHP3} * \text{V ACC P} - \text{CHP2} * \text{V DOP P}) * \left(\frac{1}{1+\text{THP1s}}\right) + \text{V GVS P}_{t=0} \end{aligned}\right\} \quad (3.10)$$

3.8 Transformer

$$\left.\begin{aligned} \text{E CAB PE} = {} & (\text{CHP8} * \text{E GYRO P}) \\ & + (\text{CHP30} * (\text{CHP10} * \text{E CAB PH} + \text{CHP29} * \text{D CA AT})) \end{aligned}\right\} \quad (3.11)$$

3.9 Sonar operator's controller

$$\text{E CA PT} = (\text{CHP11} * \text{E CAB PE}) + (\text{CHP12} * \text{THE CPT}) \quad (3.12)$$

3.10 Cable length repeater

$$\text{E CA GP} = \text{Function (D CABLE, E CA PT)} \quad (3.13)$$

3.11 Hover trim controller

$$E\ HTC\ P = (CHP16 * P\ HTC) + (CHP15 * P\ BIAS) \tag{3.14}$$

3.12 Groundspeed follow-up circuit

$$\left.\begin{array}{l}\text{If S PC is on}\\ V\ GF\ U4 = -CHP37 * \int (V\ GF\ U4)\,dt + V\ GF\ U4_{t=0} \text{ and}\\ V\ GFU\ U = CHP35 * V\ GF\ U2\end{array}\right\} \tag{3.15}$$

$$\left.\begin{array}{l}\text{If S PC is off}\\ V\ GF\ U4 = -CHP38 * \int (E\ ERR\ 1P)\,dt + V\ GF\ U4_{t=0} \text{ and}\\ V\ GFU\ U = CHP36 * V\ GF\ U4\end{array}\right\} \tag{3.16}$$

$$\left.\begin{array}{l}\text{If S TDD is on}\\ V\ GF\ U2 = CHP34 * V\ TRAN\ U * V\ GFU\ U_{t=TD} \text{ where}\\ V\ GFU\ U_{t=TD} \text{ is the value of V GFU U at time TD}\end{array}\right\} \tag{3.17}$$

$$\left.\begin{array}{l}\text{If S TDD is off}\\ V\ GF\ U2 = CHP34 * V\ TRAN\ U * V\ GFU\ U\end{array}\right\} \tag{3.18}$$

3.13 Low-pass filter

$$\left. E\ PDE\ P = \frac{CHP27 * (1 + THP5s)}{(THP6 + THP7s + THP8s^2 + s^3)} * E\ CA\ GP + E\ PDE\ P_{t=0} \right\} \tag{3.19}$$

3.14 Summing amplifier etc.

$$\left.\begin{array}{l}\text{If S PD is on}\\ E\ ERR\ 1P = -(CHP5 * V\ GVS\ P) + (CHP17 * E\ HTC\ PS)\\ \qquad\qquad\qquad + (CHP14 * E\ PDE\ P)\end{array}\right\} \tag{3.20}$$

$$\left.\begin{array}{l}\text{If S PD is off}\\ E\ ERR\ 1P = -(C\ HP5 * V\ GVS\ P) + (CHP17 * E\ HTC\ PS)\end{array}\right\} \tag{3.21}$$

$$\left.\begin{array}{l}\text{If S HT is on}\\ E\ HTC\ PS = E\ HTC\ P\end{array}\right\} \tag{3.22}$$

$$\left.\begin{array}{l}\text{If S HT is off}\\ E\ HTC\ PS = V\ DE\ US2\end{array}\right\} \tag{3.23}$$

$$\left.\begin{array}{l}\text{If S PC is on}\\ V\ DE\ US2 = V\ DE\ US1\end{array}\right\} \tag{3.24}$$

$$\left.\begin{array}{l}\text{If S PC is off}\\ V\ DE\ US2 = V\ GFU\ U\end{array}\right\} \tag{3.25}$$

$$\left.\begin{array}{l}\text{If S TD is on}\\ V\ DE\ US1 = V\ GFU\ U\end{array}\right\} \tag{3.26}$$

$$\left.\begin{array}{l}\text{If S TD is off}\\ V\ DE\ US1 = CHP33 * V\ DEM\ UU\end{array}\right\} \tag{3.27}$$

3.15 Aircraft model

$$\left. E\ AM\ P = CHP18 * \left(\frac{1}{1 + THP4s}\right) * E\ HTC\ PS + E\ AM\ P_{t=0} \right\} \tag{3.28}$$

3.16 Integrator circuit etc.

$$\left.\begin{array}{l}\text{If S PD is on}\\ E\ ERR\ 2P = E\ AM\ P + (CHP13 * E\ PDE\ P)\end{array}\right\} \tag{3.29}$$

$$\left.\begin{array}{l}\text{If S PD is off}\\ E\ ERR\ 2P = E\ AM\ P + (CHP6 * V\ DOP\ P)\end{array}\right\} \tag{3.30}$$

If S PC is on
E HP UL = (CHP19 • E ERR 1P) + (CHP20 • E INT P)
where E INT P is defined below

and

EI DT P = E ERR 2P (3.31)

If S PC is off
E HP UL = 0

and

E ERR P = (CHP19 • E ERR 1P) + (CHP20 • E INT P)
where E INT P is defined below

and

EI DT P = − CHP21 • E ERR P (3.32)

Note that if |E INT P| < |EL HP5|
$E\ INT\ P = \int(EI\ DT\ P)\,dt + E\ INT\ P_{t=0}$ (3.33)

and if |E INT P| ⩾ |EL HP5|
E INT P = |EL HP5| • SIGN (EI DT P) (3.34)

3.17 Rate and amplitude limiter

If S PC is on
E HOV P1 = (CHP22 • E HP UL) − (CHP24 • E HOV P) (3.35)

If S PC is off
E HOV P1 = (CHP22 • E HP UL) − (CHP23 • E HOV P) (3.36)

If S DC CH is on and |E HOV P1| < |EL HP1|
E HOV P4 = E HOV P1 (3.37)

If S DC CH is on and |E HOV P1| ⩾ |EL HP1|
E HOV P4 = |EL HP1| • SIGN (E HOV P1) (3.38)

If S DC CH is off and |E HOV P1| < |EL HP2|
E HOV P4 = E HOV P1 (3.39)

If S DC CH is off and |E HOV P1| ⩾ |EL HP2|
E HOV P4 = |EL HP2| • SIGN (E HOV P1) (3.40)

E HP DT = CHP25 • E HOV P4 (3.41)

If − EL HP6 < E HOV P < EL HP3
$E\ HOV\ P = \int(E\ HP\ DT)\,dt + E\ HOV\ P_{t=0}$ (3.42)

If E HOV P ⩾ EL HP3
E HOV P = EL HP3
and if E HOV P ⩽ − EL HP6
E HOV P = − EL HP6 (3.43)

3.18 Beeper selector and timer

If |E HOV P| < |EL HP4|
S POS P and S NEG P are off (3.44)

If E HOV P ⩾ EL HP4
S POS P is on (3.45)

If E HOV P ⩽ − EL HP4
S NEG P is on (3.46)

If S POS P and S MULT P are on
S FWD H is on $\Big\}$ (3.47)

If either S POS P or S MULT P or both are off
S FWD H is off $\Big\}$ (3.48)

If S NEG P and S MULT P are on
S AFT H is on $\Big\}$ (3.49)

If either S NEG P or S MULT P or both are off
S AFT H is off $\Big\}$ (3.50)

4. ASW Mode Roll Channel (Fig. 8)

4.1 Repeater platform unit

$$\text{V ACC R} = \text{CHR4} * \text{V HEH DT} \tag{4.1}$$

4.2 Vertical gyro unit

$$\text{E GYRO R} = \text{CHR7} * \text{PHI HE} \tag{4.2}$$

4.3 Doppler radar

$$\text{V DOP R} = -(\text{CHR26} * \text{VFCO}) - (\text{CHR1} * \text{V HEH}) \tag{4.3}$$

4.4 Sonar winch installation

$$\text{E CAB RH} = \text{CHR9} * \text{PHI CH} \tag{4.4}$$

4.5 Ground velocity smoother

If S RC is on
V ACC RS = V ACC R $\Big\}$ (4.5)

If S RC is off
V ACC RS = 0 $\Big\}$ (4.6)

If S PD is on

$$\text{V GVS R} = \text{CHR3} * \text{V ACC RS} * \left(\frac{1}{1 + \text{THR1}s}\right) + \text{V GVS R}_{t-0} \tag{4.7}$$

If S PD is off

$$\text{V GVS R} = (\text{CHR3} * \text{V ACC RS} - \text{CHR2} * \text{V DOP R}) * \left(\frac{1}{1 + \text{THR1}s}\right) + \text{V GVS R}_{t-0} \tag{4.8}$$

4.6 Transformer

$$\text{E CAB RE} = -(\text{CHR8} * \text{E GYRO R}) - (\text{CHR10} * \text{E CAB RH}) \tag{4.9}$$

4.7 Sonar operator's controller

$$\text{E CA RT} = (\text{CHR11} * \text{E CAB RE}) - (\text{CHR12} * \text{PHI CRT}) \tag{4.10}$$

4.8 Cable length repeater

$$\text{E CA GR} = \text{Function (D CABLE, E CA RT)} \tag{4.11}$$

4.9 Hover trim controller

$$\text{E HTC R} = (\text{CHR16} * \text{R HTC}) + (\text{CHR15} * \text{R BIAS}) \tag{4.12}$$

4.10 Low-pass filter

$$\text{E PDE R} = \frac{\text{CHR27} * (1 + \text{THR5}s)}{(\text{THR6} + \text{THR7}s + \text{THR8}s^2 + s^3)} * \text{E CA GR} + \text{E PDE R}_{t-0} \tag{4.13}$$

4.11 Summing amplifier etc.

If S PD is on

$$\text{E ERR 1R} = -(\text{CHR5} \bullet \text{V GVS R}) + (\text{CHR17} \bullet \text{E HTC RS}) + (\text{CHR14} \bullet \text{E PDE R}) \tag{4.14}$$

If S PD is off

$$\text{E ERR 1R} = -(\text{CHR5} \bullet \text{V GVS R}) + (\text{CHR17} \bullet \text{E HTC RS}) \tag{4.15}$$

If S HT is on

$$\text{E HTC RS} = \text{E HTC R} \tag{4.16}$$

If S HT is off

$$\text{E HTC RS} = 0 \tag{4.17}$$

4.12 Aircraft model

$$\text{E AM R} = \text{CHR18} \bullet \left(\frac{1}{1 + \text{THR4s}}\right) \bullet \text{E HTC RS} + \text{E AM R}_{t=0} \tag{4.18}$$

4.13 Integrator circuit etc.

If S PD is on

$$\text{E ERR 2R} = \text{E AM R} + (\text{CHR13} \bullet \text{E PDE R}) \tag{4.19}$$

If S PD is off

$$\text{E ERR 2R} = \text{E AM R} + (\text{CHR6} \bullet \text{V DOP R}) \tag{4.20}$$

If S RC is on
E HR UL = (CHR19 • E ERR 1R) + (CHR20 • E INT R)
where E INT R is defined below
and
EI DT R = E ERR 2R (4.21)

If S RC is off
E HR UL = 0
and
E ERR R = (CHR19 • E ERR 1R) + (CHR20 • E INT R)
where E INT R is defined below
and
EI DT R = − CHR21 • E ERR R (4.22)

Note that if $|\text{E INT R}| < |\text{EL HR5}|$

$$\text{E INT R} = \int (\text{EI DT R})\,dt + \text{E INT R}_{t=0} \tag{4.23}$$

and if $|\text{E INT R}| \geqslant |\text{EL HR5}|$

$$\text{E INT R} = |\text{EL HR5}| \bullet \text{SIGN (EI DT R)} \tag{4.24}$$

4.14 Rate and amplitude limiter

If S RC is on

$$\text{E HOV R1} = (\text{CHR22} \bullet \text{E HR UL}) - (\text{CHR24} \bullet \text{E HOV R}) \tag{4.25}$$

If S RC is off

$$\text{E HOV R1} = (\text{CHR22} \bullet \text{E HR UL}) - (\text{CHR23} \bullet \text{E HOV R}) \tag{4.26}$$

If S DC CH is on and $|\text{E HOV R1}| < |\text{EL HR1}|$

$$\text{E HOV R4} = \text{E HOV R1} \tag{4.27}$$

If S DC CH is on and $|\text{E HOV R1}| \geqslant |\text{EL HR1}|$

$$\text{E HOV R4} = |\text{EL HR1}| \bullet \text{SIGN (E HOV R1)} \tag{4.28}$$

If S DC CH is off and $|\text{E HOV R1}| < |\text{EL HR2}|$

$$\text{E HOV R4} = \text{E HOV R1} \tag{4.29}$$

$$\left.\begin{array}{l}\text{If S DC CH is off and } |\text{E HOV R1}| \geqslant |\text{EL HR2}| \\ \text{E HOV R4} = |\text{EL HR2}| \bullet \text{SIGN (E HOV R1)}\end{array}\right\} \tag{4.30}$$

$$\text{E HR DT} = \text{CHR25} \bullet \text{E HOV R4} \tag{4.31}$$

$$\left.\begin{array}{l}\text{If } |\text{E HOV R}| < |\text{EL HR3}| \\ \text{E HOV R} = \int(\text{E HR DT})\,dt + \text{E HOV R}_{t=0}\end{array}\right\} \tag{4.32}$$

$$\left.\begin{array}{l}\text{If } |\text{E HOV R}| \geqslant |\text{EL HR3}| \\ \text{E HOV R} = |\text{EL HR3}| \bullet \text{SIGN (E HR DT)}\end{array}\right\} \tag{4.33}$$

4.15 Beeper selector and timer

$$\left.\begin{array}{l}\text{If } |\text{E HOV R}| < |\text{EL HR4}| \\ \text{S POS R and S NEG R are off}\end{array}\right\} \tag{4.34}$$

$$\left.\begin{array}{l}\text{If E HOV R} \geqslant \text{EL HR4} \\ \text{S POS R is on}\end{array}\right\} \tag{4.35}$$

$$\left.\begin{array}{l}\text{If E HOV R} \leqslant -\text{EL HR4} \\ \text{S NEG R is on}\end{array}\right\} \tag{4.36}$$

$$\left.\begin{array}{l}\text{If S POS R and S MULT R are on} \\ \text{S STBD H is on}\end{array}\right\} \tag{4.37}$$

$$\left.\begin{array}{l}\text{If either S POS R or S MULT R or both are off} \\ \text{S STBD H is off}\end{array}\right\} \tag{4.38}$$

$$\left.\begin{array}{l}\text{If S NEG R and S MULT R are on} \\ \text{S PORT H is on}\end{array}\right\} \tag{4.39}$$

$$\left.\begin{array}{l}\text{If S NEG R or S MULT R or both are off} \\ \text{S PORT H is off}\end{array}\right\} \tag{4.40}$$

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